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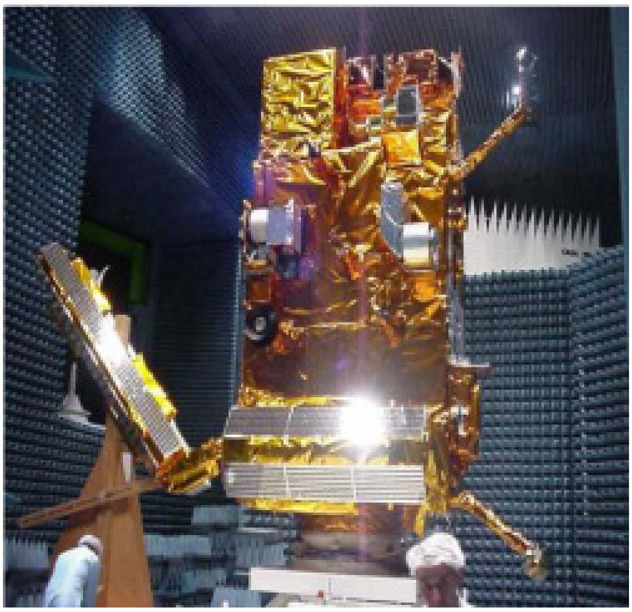

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Front cover: EMC testing of the METOP EQM spacecraft. See paper by A. Ciccolella and F. Marliani pp. 9-19.

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The International Union of Radio Science (URSI) is a foundation Union (1919) of the International Council of Scientific Unions as direct and immediate successor of the Commission Internationale de Télégraphie Sans Fil which dates from 1913.

Editorial

Our Papers

Spacecraft have a large number of complex electronic systems operating in close proximity to each other, with stringent weight (and thus shielding) limitations, and usually sharing common power and grounding systems. It is therefore no surprise that electromagnetic compatibility (EMC) on spacecraft is a particular challenge. A. Ciccolella and F. Marliani review current practices in EMC for spacecraft, and then look at future needs in the field, in their invited *Review of Radio Science* from Commission E. All of this is done from the perspective, and with examples drawn from, the European Space Agency. They begin with a discussion of the importance of EMC to spacecraft design, implementation, and operation. They then explain why EMC engineering is necessarily a process that must be carried out concurrently with the design, engineering, and testing of almost all other functions associated with creating a spacecraft. They describe the process of establishing EMC requirements for spacecraft. This includes requirements at the system level and at the equipment level. They illustrate the system-level requirements with examples from two spacecraft: GOCE and CLUSTER. They then go through a flowchart of EMC activities in a space program in detail. Finally, they look at future trends in the field. Part of the value of this paper is that it is written to be readily understandable by someone who is not an EMC engineer.

The efforts of Christos Christopoulos, A. P. J. Van Deursen, and Phil Wilkinson in bringing us this review are appreciated.

The ionosphere plays a critical role in long-distance communication. In particular, mapping conditions in the D and E regions, and in the bottom-side of the F region, can be of tremendous value. D. D. Rice, R. D. Hunsucker, J. V. Eccles, J. J. Sojka, J. W. Raitt, and J. J. Brady describe a passive sensing network designed to provide such maps on a continuous basis. The network passively monitors HF and VLF transmissions, such as those from WWV/WWVH, to obtain the basic data for the maps. The paper begins with a discussion of the roles affecting communications played by the various lower-ionospheric processes. The importance of space weather on communications is also reviewed. Out of this discussion comes a set of requirements for an observing grid that would allow weather mapping of the lower ionosphere. The authors then describe the sensors they have designed. These are built around a low-cost software-defined-radio (SDR) receiver, which allows computer control of all of the receiver's functions and of the signal processing. The receivers and the processing used are described, as well the authors' experience with the deployment and use of similar monitoring equipment over several years. They call the new monitors Space-Weather-Aware Receiving Elements (SWAREs). These incorporate ionospheric models to produce D-, E-, and F-region profiles. Ray tracing and waveguide-mode analysis can also be done. The results include detailed mapping of the area covered by the receivers and the transmitters used as beacons, and an indication of a variety of space-weather effects over these areas, as well. Having operated a prototype of this system over several paths in the US since 2002, the authors describe a number of lower-ionosphere weather effects that they have observed. They then discuss the signal analysis for both the HF and VLF signals used, and the overall data mapping. If implemented on a broader scale, such a system of receiving elements could provide an important tool for monitoring, controlling, and improving long-distance communications.

Coherent radar measurements of the Doppler velocity in the auroral E region of the ionosphere can provide important information about E-region irregularities. Such measurements can also add to the understanding of the fundamental physics of weakly ionized plasmas. In an invited paper from the Workshop on Applications of Radio Science (WARS), held February 10-12, 2008, in Broadbeach, Queensland, Australia, R. A. Makarevich reviews new information from such measurements at HF and VHF. He begins with a review of how such coherent radar measurements are made. This includes an overview of the areas covered by existing instruments. He then presents the basic theory of E-region irregularities. The central issues are the dependencies of the E-region irregularity velocities on the flow angle and the aspect angle. The flow angle is the angle between the plasma flow and the propagation vector of the electromagnetic wave. The aspect angle is the angle between the wave-propagation vector and the plane perpendicular to the field. The author then provides a detailed description and analysis of the experimental techniques and data analysis methods used. This includes a critical analysis of the many different approaches to measuring and interpreting the flow-angle and aspect-angle effects. He then shows that new coherent-radar evidence suggests that the observed variation in Doppler velocity with the flow and aspect angles can be explained by linear fluid theory. He discusses these results, as well as possible explanations for inconsistent observations. Finally, some new possible directions for observations are described.

The efforts of Phil Wilkinson in bringing us this paper are gratefully acknowledged.

A Correction

An error appeared in the December issue of the *Radio Science Bulletin* in the headline on page 62. The headline should have read "Union Resolutions & Recommendations Adopted at the Chicago GA."

Comments Requested

If you have comments, suggestions, or ideas for regular contributions that you believe would improve the *Radio Science Bulletin*, please let me know. I can be reached by e-mail at r.stone@ieee.org.

Ross

The Records of the Chicago General Assembly are now available and may be downloaded free of charge. A paper copy can be obtained via the URSI Secretariat at the cost of 40 Euro

URSI Accounts 2008

Although the world experiences currently a severe economic crisis the finances of URSI are quite healthy. This is to a large extent due to the income URSI has received from the US National Committee for the Chicago General Assembly last year. URSI is most grateful to the US National Committee for honoring its financial commitment to URSI and especially grateful to George Uslenghi for his untiring dedication which was instrumental in making the 2008 General Assembly a success. With a cost to URSI of 131.000 euro and an income of 164.000 euro which URSI received from the US National Committee, the Chicago General Assembly resulted in a net profit 33.000 euro. This was needed to offset the losses incurred in the organization of previous General Assemblies.

A settlement of arrears resulted in a larger income from the member committees in 2008. The real market value of the URSI investments dropped by less than 10% over the year 2008 which in view of the global economic evolution is a very honorable result.

The administrative costs are under control and overall URSI is in a good financial shape allowing the Board to take new initiatives that will strengthen the contributions of URSI to the further development of Radio Science.

Paul Lagasse
Secretary General

BALANCE SHEET: 31 DECEMBER 2008

ASSETS	EURO	EURO
Dollars		
Merrill Lynch WCMA	2,124.69	
Fortis	149,721.83	
Smith Barney Shearson	4,631.18	
		156,477.70
Euros		
Banque Degroof	1,001.04	
Fortis	295,408.03	
		296,409.07
Investments		
Demeter Sicav Shares	22,681.79	
Rorento Units	111,414.88	
Aqua Sicav	63,785.56	
Merrill-Lynch Low Duration (304 units)	3,268.17	
Massachusetts Investor Fund	250,958.54	
Provision for (not realised) less value	(70,264.76)	
Provision for (not realised) currency differences	(76,966.51)	
	304,877.67	
684 Rorento units on behalf of van der Pol Fund	12,414.34	
		317,292.01
Short Term Deposito		0.00
Petty Cash		370.73
Total Assets		770,549.51
Less Creditors		
IUCAF	9,274.12	
ISES	7,590.85	
		(16,864.97)
Balthasar van der Pol Medal Fund		(12,414.34)
NET TOTAL OF URSI ASSETS		**741,270.20**

The net URSI Assets are represented by:	EURO	EURO
Closure of Secretariat		
Provision for Closure of Secretariat		90,000.00
Scientific Activities Fund		
Scientific Activities in 2009	45,000.00	
Publications in 2009	30,000.00	
Young Scientists in 2009	0.00	
Administration Fund in 2009	85,000.00	
Scientific paper submission software in 2009	0.00	
I.C.S.U. Dues in 2009	5,000.00	
		165,000.00
XXIX General Assembly 2008/2011 Fund:		
During 2009 (GA 2008)		5,000.00
During 2009 - 2010 - 2011 (GA 2011)		55,000.00
Total allocated URSI Assets		315,000.00
Unallocated Reserve Fund		426,270.20
		741,270.20

Statement of Income and expenditure for the year ended 31 December 2008

I. INCOME	EURO	EURO
Grant from ICSU Fund and US National Academy of Sciences	0.00	
Allocation from UNESCO to ISCU Grants Programme	0.00	
UNESCO Contracts	0.00	
Contributions from National Members (year -1)	112,171.23	
Contributions from National Members (year)	150,998.00	
Contributions from National Members (year +1)	40,597.00	
Contributions from Other Members	0.00	
Special Contributions	0.00	
Contracts	0.00	
Sales of Publications, Royalties	1,650.88	
Sales of scientific materials	0.00	
Bank Interest	6,533.06	
Other Income	164,469.16	
Total Income		**476,419.33**

II. EXPENDITURE		
A1) Scientific Activities		143,744.52
General Assembly 2005/2008	131,131.12	
Scientific meetings: symposia/colloqiua	12,613.40	
Working groups/Training courses	0.00	
Representation at scientific meetings	0.00	
Data Gather/Processing	0.00	
Research Projects	0.00	
Grants to Individuals/Organisations	0.00	
Other	0.00	
Loss covered by UNESCO Contracts	0.00	

		EURO	EURO
A2)	Routine Meetings		8,895.11
	Bureau/Executive committee	8,895.11	
	Other	0.00	
A3)	Publications		33,329.03
B)	Other Activities		8,916.00
	Contribution to ICSU	4,916.00	
	Contribution to other ICSU bodies	4,000.00	
	Activities covered by UNESCO Contracts	0.00	
C)	Administrative Expenses		156,380.48
	Salaries, Related Charges	74,836.26	
	General Office Expenses	5,088.75	
	Travel and representation	4,447.26	
	Office Equipment	691.28	
	Accountancy/Audit Fees	5,414.75	
	Bank Charges/Taxes	3,109.79	
	Loss on Investments (realised/unrealised)	62,792.39	
	Total Expenditure:		**351,265.14**

Excess of Income over Expenditure	125,154.19
Currency translation difference (USD => EURO) - Bank Accounts	2,910.17
Currency translation difference (USD => EURO) - Investments	3,296.69
Currency translation difference (USD => EURO) - others	3,001.73
Accumulated Balance at 1 January 2008	606,907.42
	741,270.20

Rates of exchange:

January 1, 2008	$ 1 = 0.6860 EUR
December 31, 2008	$ 1 = 0.6990 EUR

	EURO
Balthasar van der Pol Fund	
684 Rorento Shares: market value on December 31	
(Aquisition Value: USD 12.476,17/EUR 12.414,34)	29,521.44
Book Value on December 31, 2008/2007/2006	12,414.34
Market Value of investments on December 31, 2008-2006	
Demeter Sicav	66,089.10
Rorento Units (1)	561,080.00
Aqua-Sicav	88,191.01
M-L Low Duration	1,889.09
Massachusetts Investor Fund	105,106.35
	822,355.55
Book Value on December 31, 2008/2007/2006	304,877.67

(1) Including the 684 Rorento Shares of the van der Pol Fund

APPENDIX: Detail of Income and Expenditure

	EURO	EURO
I. INCOME		
Other Income		
Income General Assembly 2005	0.00	
Income General Assembly 2008	133,812.91	
Young Scientist Support (Japan)	4,116.00	
Support Koga Medal	686.00	
Closure Radio Science Press	18,875.25	
Commission B + C	2,000.00	
Mass Investors Growth Stock Fund	4,908.48	
Other	70.52	
		164,469.16
II . EXPENDITURE		
General Assembly 2008		
Organisation	2,123.84	
Vanderpol Medal	1,983.21	
Young Scientists	22,926.12	
Expenses officials	78,258.62	
Student Support	25,839.33	
		131,131.12
Symposia/Colloquia/Working Groups:		
Commission A	0.00	
Commission B	0.00	
Commission C	868.63	
Commission D	1,896.74	
Commission E	420.79	
Commission F	500.00	
Commission G	2,165.29	
Commission H	2,029.00	
Commission J	4,732.95	
Commission K	0.00	
Central Fund	0.00	
		12,613.40
Contribution to other ICSU bodies		
UNESCO-ICTP	0.00	
FAGS	2,000.00	
IUCAF	2,000.00	
		4,000.00
Publications:		
Printing ‘The Radio Science Bulletin’	12,271.87	
Mailing ‘The Radio Science Bulletin’	21,057.16	
URSI Leaflet	0.00	
		33,329.03

EMC in Space Systems : Current Practices and Future Needs - The ESA Perspective

A. Ciccolella
F. Marliani

Abstract

Space systems inherently belong to the category of complex systems, having specific unique traits. This paper presents an overview of the electromagnetic compatibility (EMC) activities carried out for a space mission. It addresses the impact of the EMC discipline on the spacecraft's procurement, the definition of the requirements, and the EMC program, with a number of real life examples. Finally, trends and future needs are discussed.

1. Introduction

The practical control of electromagnetic interference (EMI) generally evokes esoteric notions for the public, especially when complex systems are considered. However, extensive research and standardization activities have been carried out in the last decade, with the objective of identifying and consolidating EMI-suppression practices and test methods, and developing advanced analysis techniques for EMC. Space systems inherently belong to the category of complex systems that have specific unique traits. Examples include interaction with the harsh space environment [1], the impossibility of maintaining or refurbishing the spacecraft after launch, the unconventionally tight requirements for onboard payloads [2-6], the astonishing costs involved, and so on. In this context, EMC is the domain where engineers are exposed to the widest contrast between the complexity of technical electromagnetic issues, and the pragmatic side of system engineering. Going straight to the heart of the matter, this paper deals with the following questions:

- How important is EMC for spacecraft?
- Is it a standalone activity, or a concurrent engineering discipline?
- What is the process for establishing EMC requirements?
- What is the flow of the EMC activities in the framework of a space program?
- What are the future needs?

The relevant answers, supported by real-life examples, will hopefully give an exhaustive impression of the EMC processes, methods, and tools for the space business. These will also hopefully illustrate the rigor of a true systems approach, and the labor of knowledgeable professionals in industry, research, centers and European international organizations. Only these allow the EMC success of a space mission.

2. The Importance of EMC for Spacecraft

All spacecraft require EMC. Its verification is always the subject of a dedicated test campaign for acceptance by the procuring body. This fact establishes the implicit contractual importance of the discipline.

EMC engineering ensures that space vehicles and their parts do not produce or suffer from EMI throughout the program's life cycle. This must be attained through built-in-design compatibility – instead of after-the-fact remedial measures – which is the real indicator of success.

The rapid development of technology has increased not only the number of onboard pieces of electrical equipment, but also their complexity. The effectiveness of performing any single basic function is hence presently dependent on the efficient performance of many other functions. Faster and more sensitive electronic technologies for space applications, and the use of wider bandwidths in the design of equipment, drive new and challenging requirements for the flight hardware, with increasing pressure to accommodate the hardware in ever-smaller and more-crowded spaces. As a result, this unfortunately increases the

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This is one of the invited *Reviews of Radio Science* from Commission E.

probability of performance degradation by undesired electromagnetic interaction.

Depending on the nature of the mission, EMI can upset spacecraft in a variety of ways. These range from direct-current (dc) effects, such as electrostatic charging [7-11] and magnetization [12, 13], to alternating-current (ac) and transient effects. The latter include both conducted and radiated effects [14-16], which include interference hazards at the intra-system level (i.e., within the spacecraft's avionics and payload elements), and the inter-system level (between the launch vehicle and spacecraft, or in the framework of the space systems' docking [17]). The interaction with the natural space environment (e.g., radiation, plasma, cosmic rays, occurrence of geomagnetic sub-storms), which may cause potentially disruptive effects (e.g., electrostatic discharges), is another issue that needs to be taken into account [18-20].

The consequences of EMC-related disturbances on spacecraft can include nuisances, which jeopardize the correct performance of the mission and reduce the efficiency of some functions. The consequences can also be catastrophic. These can lead to irreversible loss of some operational capabilities, with relevant impact in terms of scientific and programmatic yields, cost overruns, and schedule impacts. The effects of these disturbances can be temporary telemetry interruption, noisy science data, and permanent damage of power supplies, accidental tripping of the protection devices, false commanding, and instability of the power distribution subsystem, to mention just a few [21].

It is apparent that EMC involves risk management, and implies a working knowledge of the spacecraft's subsystems. The EMC process requires cost-effective considerations throughout every phase in the system's life cycle. In fact, EMC control decisions are particularly susceptible to the influence of cost-effective tradeoffs. Analysis, testing, and correction involve considerable program expenses. Every effort should be made to apply a commensurate level of EMC work and provisions to achieve the mission's objectives, while safeguarding reliability. Therefore, EMC engineering also encompasses programmatic responsibilities.

The aspects outlined here show the technical and programmatic importance of EMC for the space business as a critical activity for meeting cost, schedule, and performance goals.

3. A Concurrent Engineering Discipline

From the above short overview, it emerges that EMC for space systems interfaces with several disciplines. However, it is per se a subject for specialists. The control of noise and interference on spacecraft involves generic applications, covering many engineering domains, knowledge of which is a key issue for successful implementation. In general, EMC is an integral part of the overall spacecraft-system engineering process. Understanding of electromagnetic theory and modeling techniques, as well as being familiar with sophisticated practices for both manufacturing and testing, are hence necessary but not always sufficient conditions for implementing a successful EMC program for spacecraft.

The following list of functions gives a non-exhaustive idea of the mutual interactions that influence and are influenced by the EMC discipline:

- Program and mission management
- System engineering
- Electrical design engineering
- Mechanical engineering
- Quality, safety, reliability, and product assurance
- Configuration management
- Environmental design
- Ground support equipment engineering
- Manufacturing, assembly, integration and test engineering
- Parts, materials, and processes
- Payload Engineering

Adequate definition and management of the interface specifications is also essential, in order to enforce correct EMC engineering solutions with little impact on the other disciplines. In principle, EMC is thus a cross-disciplinary activity that requires full system visibility. As such, EMC engineers are part of the system team.

The above concepts are applicable to all ESA (European Space Agency) programs that rely on system specifications. The underlying principle is to establish system-performance requirements, which in turn drive a design that directly controls the interactions between individual pieces of equipment or subsystems. In other words, the objectives of the mission and the payloads drive the requirements and the design of the spacecraft. However, for specific cases, the converse is viable. In fact, some complex space systems – such as the International Space Station and the former soviet orbital station, MIR (from the Russian word "ᑕ," which can mean both *peace* and *world*) – have a configuration that evolves in time. These include orbit replaceable units (ORP), which are generic payloads of arbitrary nature. These orbital infrastructures are platforms for micro-gravity and manned-space-related studies, where the driving requirement is essentially human safety. Payloads have to comply with severe safety rules and have to meet equipment-level limits, which should effectively control both the equipments' contribution and tolerance to the environmental levels with abundant margins. It is thus the payload that shall fit the platform requirements, rather than vice versa. If a payload fails for any reason, it must fail safely. Consequently, in this particular context, the EMC discipline has less-frequent system interaction than in the previous cases, and more-pronounced relations with the safety process.

4. The Process of Establishing EMC Requirements

4.1 System-Level Requirements

The system specification approach, which is the most common in ESA spacecraft, is outlined hereinafter. At the beginning of a space program, the System Requirement Document (SRD) is issued, which is a fundamental part of the Invitation to Tender (ITT), i.e., the first step of the procuring activity. The System Requirement Document specifies the mission's scientific objectives, and, as a consequence, the first level of the technical performance that the spacecraft shall fulfill, in a broad sense. The EMC system-level requirements of the spacecraft can be either explicitly addressed in the System Requirement Document, or can be derived from the mission's goals.

The development of this process is now illustrated with two complementary real-life examples, addressing the same topic: magnetic cleanliness control. Magnetic cleanliness control constitutes the set of design and manufacturing rules, and assembly, integration, and verification (AIV) activities at large, which are necessary to ensure that the magnetic characteristics of spacecraft do not interfere with the quality of the scientific data [22-25].

4.1.1 CLUSTER

CLUSTER is an ensemble of four spacecraft. These are presently operational, carrying highly sensitive magnetometer experiments for measuring the magnetic field in the magnetosphere. The magnetic fields of interest are within the range of few nanotesla [26, 27]. In order to avoid interference with the science data, the spacecraft-generated magnetic disturbance can not exceed 250 pT at the magnetometer's location, with a stability of ±100 pT per 100 s. The EMC system-level requirement was therefore straightforward, in this case. Not only did the requirement implicitly put constraints on the magnetic cleanliness of the spacecraft, but also it had implications for the mounting position of the sensor and, consequently, on the mechanical complexity of the telescopic boom supporting the magnetometer.

A deep analysis was made to trade the boom length off against the estimated spacecraft-generated magnetic field. The starting point was the experience acquired with previous spacecraft, such as Helios 1-2, GEOS, Giotto, Ulysses, and Cassini-Huygens. These conducted extensive and successful magnetic-cleanliness programs to ensure the success of the mission. Each unit of the spacecraft was represented by a magnetic dipole, the magnitude of which was derived from data available from previous missions that embarked with similar units. Each dipole was assumed to be at the center of the corresponding unit in the spacecraft's system of reference. These were the inputs for running a Monte Carlo analysis that computed the probability density distribution of the magnetic field around the spacecraft. This was done in order to optimize the boom length to meet the magnetic requirement, within a given margin of confidence.

Simultaneously, considerations of magnetic cleanliness had a high priority during the design phase. This imposed severe screening of materials, parts, and process for magnetic properties; degaussing of the unavoidable soft magnetic parts; and, eventually, dc field compensation [28]. Magnetic shielding was not permitted, since the shielding material could be easily magnetized during handling, vibration, launch, etc., and would produce an unknown variable field that could not be controlled during flight. It was therefore preferable to accept a known (but still small) permanent field background, which was stable, instead of having a lower but variable field produced by the soft magnetic material. Many other provisions and precautions have been implemented throughout the

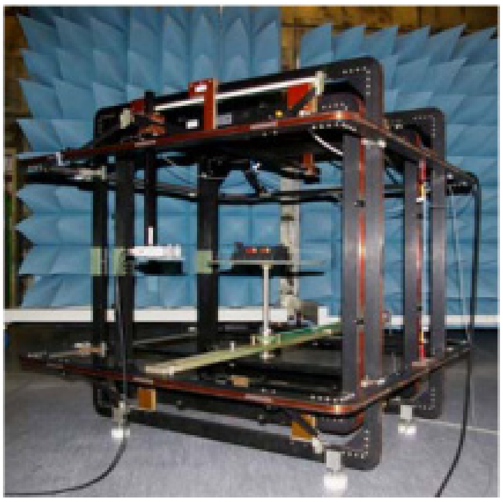

Figure 1. The magnetic-coil facility (MCF) at ESTEC. The magnetic-coil facility is used to determine (i) the permanent magnetic momentum of a test object by taking several readings of the magnetic field produced in a zero magnetic background, and (ii) the induced field momentum by illuminating the test object with a sequence of magnetic-field vectors.

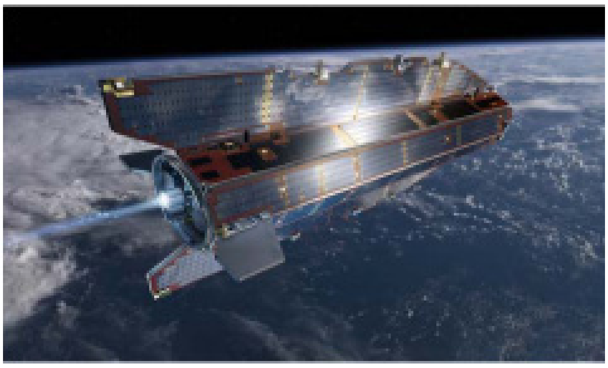

Figure 2. An artist's impression of the GOCE satellite.

CLUSTER life cycle under the program-integrator's responsibility. These have ranged from handling procedures to magnetic-compensation techniques (e.g., back-wiring of solar arrays) and design (i.e., balanced-differential interfaces, synchronization of dc-dc converters, etc.).

The 250 pT requirement was finally verified by tests and analyses. A spacecraft magnetic model was built by representing each unit by a multi-dipole equivalent source, extracted from equipment-level measurements (Figure 1) using a least-square technique [29, 30]. This model also allowed the identification of the critical units that required compensation techniques, e.g., gluing additional magnets in such a way that the main moment of the unit was decreased. The magnetic-field values predicted with the spacecraft model were then compared to the results of the system test with the magnetometer boom deployed [13, 31].

4.1.2 GOCE

GOCE [32, 33] is a spacecraft designed to determine the stationary Earth's gravity field – the geodic height and gravity anomalies – with high accuracy (1 cm and $10^{-6} g$, respectively) and spatial resolution (100 km), after ground data processing (see Figure 2 for an artist's impression). An electrostatic gravity gradiometer, composed of six tri-axial accelerometers, will measure the gravity-gradient tensor along the GOCE orbit (250 km circular, inclination 96.5°). The principle of operation of the gradiometer relies on measuring the forces that maintain a "proof mass" at the center of a specially engineered "cage." In each accelerometer, a platinum-rhodium proof mass (4 cm × 4 cm × 1 cm, 320 g) is suspended by electrostatic forces, and actively controlled in six degrees of freedom at the center of a cage via sixteen electrodes machined on the internal walls. A voltage is applied to the proof mass through a gold wire of 5 mm diameter, which also drains the excess charged particles from the proof mass. The control voltages are representative of the accelerations of the proof mass relative to the cage.

The gradiometer's specifications require that the total measurement-error spectral density of the gravity-gradient tensor's diagonal components can not exceed 4 mE/Hz$^{1/2}$ in the measurement bandwidth of 0.005 Hz to 0.1 Hz [33] ($1\ \mathrm{E} = 10^{-9}\ \mathrm{s}^{-2}$ is a unit of gravity gradient called the Eotvos).

These requirements do not appear very pertinent to EMC. However, they do influence the magnetic design of the spacecraft. In fact, although weakly paramagnetic, the accelerometer mass couples with any external magnetic induction field of strength **B** by virtue of its magnetic susceptibility. The magnetic-induced force disturbs the measurement of the acceleration, according to the following approximate formula:

$$\mathbf{a}_m = \frac{1}{2}\frac{\chi_m}{\mu_0}\frac{V}{m}\alpha\nabla\left(\mathbf{B}\bullet\mathbf{B}\right),$$

where $\mathbf{a}_m$ is the acceleration induced by the magnetic disturbances; *V* and *m* are the volume and the mass of the proof mass, respectively; μ_0 is the vacuum magnetic permeability; χ_m is the magnetic susceptibility of the material (3×10^{-4} for the specific alloy used in GOCE); α is the magnetic shielding of the accelerometer housing; and $\mathbf{B} = \mathbf{B}(\mathbf{r},t)$ is the external magnetic induction field.

The magnetic induction field, $\mathbf{B}(\mathbf{r},t)$, follows a stochastic process, including both the natural space environment and the spacecraft-induced disturbances. As such, it is more conveniently characterized in terms of its power spectral density (PSD), in line with the initial definition of the gravity gradient spectral density error.

The high sensitivity of the scientific requirement did not allow the spacecraft integrator to neglect this contribution, which had to be necessarily accounted for in the overall satellite error budget. A portion of the specified error for gradient fluctuation was hence allocated to magnetic disturbances following system-level considerations. The system-level requirement was then apportioned at the equipment level as a function of the preliminary satellite layout with various techniques (e.g., Monte Carlo), under the assumption that any equipment could be modeled by magnetic dipoles. The calculation of the apportioning exercise brought values of magnetic field fluctuations of a few nT/Hz$^{1/2}$, measured at a distance of 1 m from the equipment. Apart from the technical consideration of this requirement – which is apparently stringent – it could have potentially brought severe programmatic drawbacks, impacting both the cost and the schedule of the program. In fact, any equipment would have required a long testing time, uncommon facilities, data processing, and difficult retrofit in case an out-of-specification situation was detected. The program integrator performed a tradeoff, the results of which showed that sufficient magnetic shielding on the accelerometer heads was the more cost-effective solution in order to reduce excessive use of program resources.

These two examples addressed the same topic (magnetic requirements), and were handled with different but equally effective approaches. They allow insight into the complexity and the programmatic responsibilities involving EMC.

There are numerous cases where EMC directly influences spacecraft system design. They are so mission-specific that it is impractical to give a universal paradigm, covering all the possible cases, here. For system-level requirements, it is hence convenient to proceed with examples. This time, let us briefly consider the different implementation of a fundamental EMC concept: the spacecraft's power-bus grounding.

A well-posed electrical grounding architecture is the primary ingredient for achieving EMC at the spacecraft level in a cost-effective way. Grounding provides a common voltage reference for spacecraft electronic equipment and subsystems, while minimizing EMI and unintentional interactions between them. Different grounding concepts have pros and cons, including reliability considerations that are the subject of deep tradeoff studies since the conceptual phase of the spacecraft's definition [34]. A conclusion must be reached before the equipment's EMC design takes place.

A widely used architecture in spacecraft, adopted by a number of ESA projects (e.g., ENVISAT, Herschel and Planck, SMART-1, ROSETTA, MARS Express, and BEPICOLOMBO, to mention a few) is distributed single-point grounding (DSPG). The basic principle is to isolate power networks in the system through dc/dc converters, to minimize the mutual interactions. Generally, the negative terminal of the battery is connected to ground.

On the contrary, Russian spacecraft have the main power distribution isolated with respect to the chassis. More precisely, the return power line is connected to the chassis through a bleed resistor, shunted by a capacitor (typically a few kΩ and a few hundred nF, respectively) close to the power source. The resistor ties the power bus to the chassis potential, and simultaneously limits the current flowing onto the structure in case of an isolation fault of the main power bus. The Russian system has an intrinsic single-failure tolerance against short circuits of the primary bus that could cause a loss of mission. The disadvantage is increased common-mode noise at the user interfaces, and, consequently, an increased radiated emission from the power harness [35]. The bus users hence have to make provisions for common-mode immunity. This can be tolerable if performance is traded against the mission loss.

Figure 3 reports a typical example of the common-mode noise (i.e., the voltage between the positive line and the chassis, the return line and the chassis) taken from the Automated Transfer Vehicle (ATV) [36]. The ATV is an automatic, unmanned space-transport vehicle developed by the European Space Agency. It carries cargo and supplies from Earth to the International Space Station (ISS). The ATV docks to the Russian segment of the ISS, which provides the necessary power with a 28 V regulated power bus that presents the configuration described above.

Reliability considerations have suggested using this grounding architecture for critical interplanetary missions, especially those using radioisotope thermoelectric generators (e.g., Huygens-Cassini, Voyager, and Galileo, to mention a few examples). In fact, nuclear radiation in the long term may alter the properties of the insulation materials inside the generator container, leading to current leakage or short circuits. Launch vehicles (e.g., ARIANE 4) also have such a grounding architecture. Of course, systems using the primary power bus must be designed in order not to violate the isolated-grounding concept. The success of many space missions demonstrates the validity and sometimes the necessity of this approach.

Pyrotechnic initiator units [37] widely use the isolated grounding architecture, even when the rest of the spacecraft follows a different grounding architecture at the system level. The reason is always the same: reliability. When an electro-explosive device (EED) blows, the conductive hot plasma generated by the powder charge may close the loop from the positive power line to the chassis, causing a persistent short circuit. In this case, currents of the order of 10 A can flow onto the chassis, giving rise to magnetic

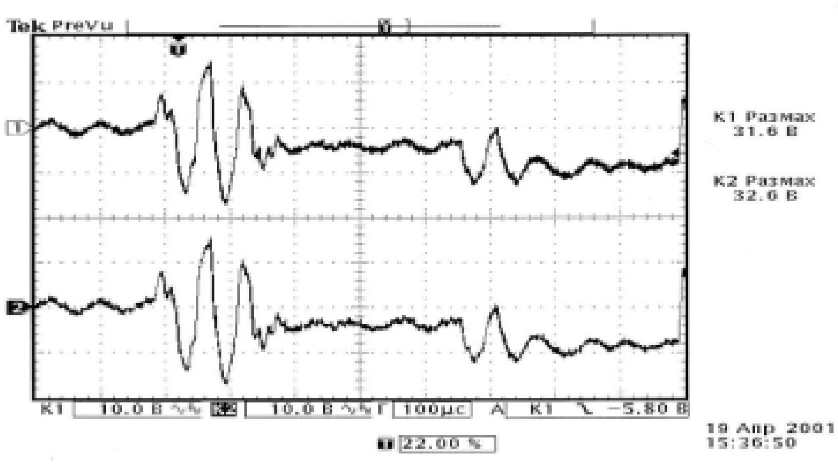

Figure 3. A typical common mode voltage (~30 volts) on floating power buses. This is a transient measured at the interface between the Automated Transfer Vehicle and the Russian Service Module in March 2001 (the test was carried out with a representative interface).

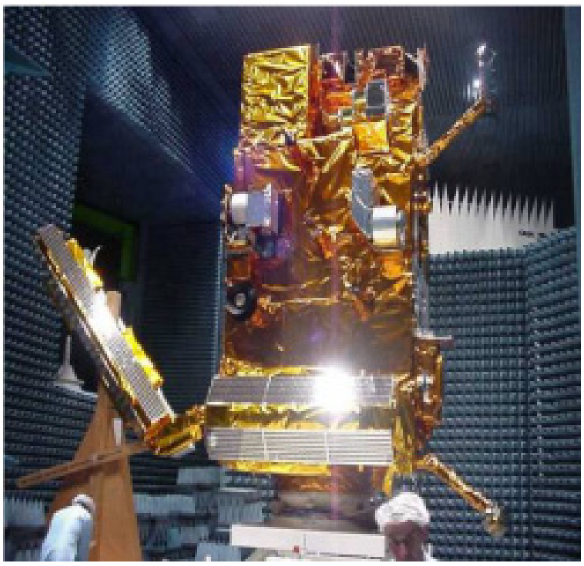

Figure 4. EMC testing of the METOP EQM spacecraft.

coupling into nearby circuits, until possibly exhaustion of the available power. An isolated power bus with an appropriate bleed resistor can be a simple remedy that will limit the consequences of this phenomenon.

4.2 Equipment-Level Requirement

While the definitions of the system-level requirements are directly or indirectly derived from the mission-specific demands, not all the equipment-level requirements can follow the same process. An apportioning from system to equipment level is possible only for certain unconventional requirements. Otherwise, EMC engineers have recourse to tailored standards (e.g., ECSS [15-16]), or to the mature experience of previous projects.

Typical unit-level requirements are the radiated emissions and susceptibility notches:

- To cover the bands used for telemetry and tele-command (TT&C) signals (e.g., unit-level emissions are limited to 10 dBμV/m in the tele-command band around 7.2 GHz for Herschel-Planck, and even-more-stringent requirements are applied to deep-space missions)
- For launcher compatibility ([38] provides the essential data on the Ariane 5 launch system, which together with Soyuz and Vega constitutes the European Space Transportation union), and
- To protect relay communication (e.g., the UHF link between the orbiter and the rover of the EXOMARS mission).

When very sensitive payloads are embarked, specific requirements and design measures are implemented to assure adequate EMC performance of the satellite. In [39], experience was presented from the METOP satellite (Figure 4), a meteorological satellite program jointly established by ESA and EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites). METOP features very sensitive receivers in the frequency range of 120-406 MHz for the search and rescue instrument (S&R). In order to ensure the compatibility with the METOP search and rescue receivers, the radiated emissions from the whole satellite have to be as low as −28 dBμV/m [39].

5. The Flow of the EMC Activities in the Framework of a Space Program

The final objective of the EMC activities performed throughout the development of any space system is to ensure that during the spacecraft's lifetime – from equipment integration over launch until spacecraft decommissioning – the system is self compatible, and neither causes disturbances to other systems nor suffers loss of performance due to other systems or any external environment. This goal is pursued by a balanced combination of standards, guidelines, the heritage of previous projects, and modeling and testing spanning from the earliest stage of the program to the final integration of the space system. In the following, the skeleton of the procedure and the relevant documentation aimed at ensuring the attainment of system-level EMC are presented.

The main documents tailored towards the system requirements are:

- EMC Specification: contains the requirements at the system, subsystem, and unit level.
- EMC Control Plan: describes methods, means, and rules that will be followed throughout the project to guarantee compliance with the requirements as defined in the EMC Specification.
- EMC Test/Verification Plan and Procedure: presents the test setup and procedures to verify the specifications.
- EMC Test/Verification Report: reports the test results and the relevant non-conformance.
- EMC Analyses: contains all the ancillary analyses carried out in support of design and testing activities, e.g., predictions of intra-system EMI/EMC based on equipment EMI characteristics to assess design solutions such as filtering, grounding, and shielding.

The above documents are managed by the EMC engineers, and are periodically updated throughout the development phases of the system. Several milestones trace the life of the spacecraft. Failure to complete any of them precludes the possibility for stepping to the subsequent milestone.

A non-exhaustive list of data/deliverables that must be completed for each milestone is presented hereinafter [40].

5.1 Request for Proposal (RFP) or Response to Invitation to Tender (ITT)

In the preparation of the response to the Invitation to Tender, the EMC engineers study and define the known operational environments. They identify the functional criticality for all the equipment and subsystems that are classified in adequate categories of risk. At this stage of the program, a safety margin is defined for critical functions and electro-explosive devices (EEDs), to account for lifetime degradation of circuits and circuit protection. Typically, 20 dB are allocated for electro-explosive devices, and 6 dB for signal, power, and control lines [15, 16]. Finally, general guidelines (e.g., separating signals and primary power bus, selecting the frequencies of dc/dc converters outside signal bands, twisting and shielding the harness with the appropriate twist rate, etc.) are defined and made applicable to the procurement of units and subsystems, as well as to the integration of the system.

5.2 System Readiness Review (SRR) or Requirement Definition Review (RDR)

At the system readiness review, the EMC specification must be consolidated with requirements at the system, subsystem, and unit levels. Typical requirements are grounding, bonding, in-rush current, conducted (continuous-wave and transient) and radiated emissions, as well as susceptibility, electrostatic discharge, and magnetic cleanliness control [15, 16]. The EMC engineer is also responsible of the definition of the margin-verification methods at the system level in the EMC Control Plan. The verification of the compatibility of the system is de facto achieved by imposing and demonstrating a safety margin between the susceptibility threshold of the units and the actual noise at the system level under worst-case conditions [15, 16].

The EMC guidelines are final consolidated, with special precautions for the critical cases. As seen in the previous sections, for magnetically sensitive spacecraft (e.g., CLUSTER, GOCE) several preventive measures have matured along the years. Nowadays, very good reliable engineering practices are known and implemented [23-26].

5.3 Preliminary Design Review (PDR)

At the preliminary design review, the most critical EMI aspects must be identified (in EMC Analyses), and appropriate countermeasures consolidated (in the EMC Control Plan). The impact of the components-off-the-shelf (COTS) on the system and their EMI/EMC performance are assessed (in EMC Analyses). An accurate grounding diagram of primary/secondary power, units, shields, and principal interfaces (EMC Control Plan) is built. The EMC engineer finally consolidates the model philosophy and the relevant verification methods (in the EMC Control Plan) that will be followed throughout the course of the program.

The principal spacecraft models are the avionic model (AVM), the engineering/electrical qualification model (EM/EQM), the proto flight model (PFM), and the flight model (FM).

The applicable verification methods can be (i) analysis; (ii) review of design (e.g., correct use of shielded twisted wires, shield grounding, power isolation by review of drawings); (iii) inspection to verify the conformance of drawings, the use of proper parts and materials, e.g., harness separation, correct routing, etc.; (iv) testing to demonstrate the compliance with the requirements during different stages of the project (i.e., development, qualification, and acceptance); and (v) similarity applied to equipment/subsystems that have been previously qualified to the same or more severe environments.

5.4 Critical Design Review (CDR)

Between the preliminary design review and the critical design review, all the units and subsystems are designed, assembled, and qualified. The System EMC Control Plan is updated with the unit/subsystem results (the EMC Test Report), and any potential criticality is identified and the relevant countermeasures are decided. The EMC managers evaluate all requests for waiver (RFW) and non-conformance reports (NCR), and dispose of the relevant actions to be completed prior to the final system-level test. The system level test, to be performed before the flight acceptance review, is fully defined in light of the results at the unit and subsystem levels.

5.5 Flight Acceptance Review (FAR)

In the preparation for the flight acceptance review, limited system-level testing is performed, in order to collect the ultimate results necessary to complete the system-level analyses. The emissions and susceptibility tests conducted are typically confined to those areas that have shown a

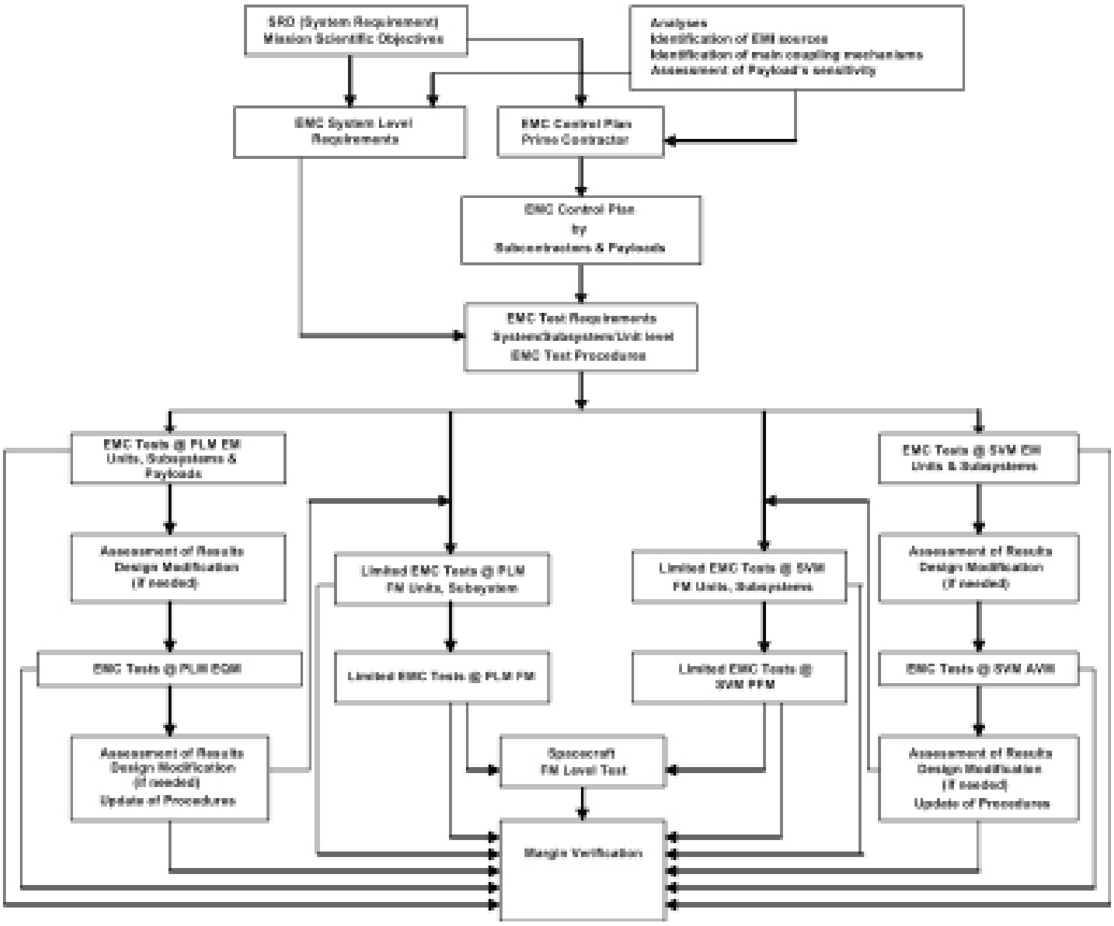

Figure 5. A flowchart of EMC program activities.

certain degree of marginality at the sublevel, or that constitute the core power-distribution points of the spacecraft. Radiated emission and susceptibility tests are carried out to prove the system's margin (6 dB). Particular attention is devoted to the measurements of specific notches (e.g., tele-command, launcher, sensitive payloads). The final issues of the EMC analyses and of the EMC Test/Verification Report are prepared, in order to demonstrate the electromagnetic compliance of the system with an adequate margin of safety.

The activities described in the sections above are summarized in the flowchart presented in Figure 5. This constitutes an overview of the various stages of the EMC program adopted by many spacecraft. For the sake of generality, the flowchart presents an approach based on analyses and tests at the service-module level (SVM: the part of the satellite that ensures power supply, attitude control, and RF communication with the ground station); the payload-module level (PLM: the part of the satellite that carries out the scientific mission); and the system level. However, the reader should be aware that for the sake of cost reduction, some spacecraft follow a reduced program, possibly with testing only of the fully integrated satellite.

6. Conclusions, Trends, and Future Needs

The limited budget for space-related industry, and the simultaneous introduction of innovative electronic technology and services, require a rationalization of the EMC discipline. The increasing complexity of spacecraft systems, i.e., buses, payloads, and their mutual interaction, calls for EMC design and verification based on a systematic analytic methodology. The insufficient a priori knowledge of large electromagnetic systems – including the details of their elements and the mutual-interaction paths – plays a significant role in consolidating the EMC discipline as prominently empirical.

EMC deals intrinsically with electromagnetic noise, which is rigorously described by the methods of stochastic process theory. In many instances, very sensitive scientific payloads (e.g., LISA, Herschel and Planck, LISA Pathfinder, etc.) specify their tight science requirements in terms of power spectral density, rather than in those units conventionally adopted by the EMC community. The verification of such requirements and their implication for the spacecraft's specification and design deserves a great deal of analysis that still needs to be finalized. Although classical EMC requirements are in place to impose canonical design criteria at the equipment level, to limit the generated disturbances and to ensure that sufficient immunity is built in, a rigorous treatment of the science requirements and their implications for the equipment level is still to come.

EMC engineering has several issues in common with reliability related disciplines. These regularly rely on statistical approaches [41], especially when we consider the margin evaluation and the overall functional assessment at the system level.

The above considerations point the next generation of electromagnetic tools for intra-system compatibility toward a probabilistic approach, i.e., where the probability of having interference exceeding a given threshold at a predetermined point is the output. The feasibility of achieving estimated solutions with moderately high statistical accuracy depends critically on how effectively available information is exploited [41].

New communication and information devices and services in space, together with the trends toward further miniaturization of electronic components, pose new EMC problems. Ultra-fast digital electronics, clock frequencies beyond 1 GHz and power-supply switching frequencies above 1 MHz, coexisting in densely packed printed circuit boards (PCB), require further research to achieve reliable design and analysis. The frequency range of interest will easily exceed the upper limit of today's EMC methods, especially for conducted disturbances. Not only does this put into discussion the validity of the usual EMC requirements, but also it asks for EMC modeling and instrumentation readiness to deal with this emerging technology for space applications.

Innovative testing concepts, supported by new-generation sensors and devices, constitute the essential supplement to face the present and future technological developments. Relying on existing test instruments (i.e., oscilloscopes and spectrum analyzers) and on the physics of the EMC phenomena, the new testing approaches focus on both the reduction of cost and time, while bringing added value to system verification. A valid alternative could consist of using time-domain techniques to the maximum extent for system verification [42, 43]. Of paramount importance is further investigation of alternative methods to radiated tests, which are expensive in terms of facilities and test time. This imposes a cost burden on EMC development and testing, especially for small and medium enterprises. Despite these costs, such tests are afflicted by inherently large uncertainties in the results. Bulk-current injection (BCI) [44-46] and stirred-mode or reverberation chambers [47] could be both more efficient and less expensive.

Numerical three-dimensional solvers also constitute valid support for EMC engineers for the selection of appropriate solutions during the design phase, and the detection of possible anomalies and troubleshooting analyses. They can therefore lead to cost and time savings. In the last decade, electromagnetic numerical simulations of large-scale systems have shown significant progress, profiting from the growth of computational electromagnetics and computer performance. A good overview of the current numerical-simulation capabilities for modeling complex systems, including structure, cabling, and electronic equipment, was provided in [48].

The European know-how for the space EMC discipline has the potential to both keep pace with the technology evolution, and to foster industrial competitiveness in the market at large. Institutional R&D funding with space agencies, in order to harmonize EMC practices, methods, and standardization for this specific market, appears the only viable strategy for success.

This concept constitutes the core of the desired roadmap to future developments, which can be summarized as follows:

- Provide the tools to evaluate and control electromagnetic interference effects that clearly have an impact on economics and competitiveness;
- Cut the test costs and improve analysis capability;
- Improve technology readiness for future missions and needs by developing low-cost EMC instrumentation with optimized performance; and
- Produce and maintain the technical standards necessary for the European market in space EMC and related areas, accounting for cost/benefit analysis and the inherent business-impact assessment.

EMC is the result of the efforts of the project team technically concurring to achieve the objectives of a space mission. There are still many issues to clarify and many challenges to face, but the variety of options and the continual technical challenges nourish the charming nature of this discipline.

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Characterizing the Lower Ionosphere with a Space - Weather - Aware Receiver Matrix

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Abstract

Current ionospheric models are very good at specifying regular diurnal and seasonal variations of the E and F regions of the ionosphere. Less is known about the behavior of the D region, although progress has recently been made with models such as the Data-Driven D-Region (DDDR). However, significant departures from modeled behaviors are observed even during solar minimum conditions, due to complex ionospheric weather effects arising from both solar activity above and terrestrial atmospheric perturbations below. The D-region perturbations directly affect VLF communications, and also affect daytime absorption of frequencies from LF through HF. Perturbations in the E and F regions affect HF propagation, and may impact transionospheric communications at much higher frequencies.

In order to characterize ionospheric weather and its effects on operational systems, better observing networks are needed, comparable to those utilized to study and forecast mesoscale (10-1000 km) tropospheric weather. Current terrestrial observatories used in space-weather studies are widely separated geographically. They often do not record continuous observations, making it difficult to quantify the spatial and temporal behavior of space-weather phenomena.

We describe a passive sensor network designed to map conditions in the D and E regions and in the F-region bottomside on a continental scale, based on continuous monitoring of propagation effects on signal strength in the VLF through HF frequency range (10 kHz to 30 MHz.) This network is inexpensive to build and to operate, providing information about ionospheric conditions along the monitored signal paths, and enabling space weather effects to be inferred. This weather information is used to update mesoscale D- and E-region models, which are in turn used by radio-propagation modeling tools to analyze signal observations.

A prototype network has been deployed in the western United States, with six fixed and two transportable sensors. Data from the prototype and from an earlier HF-only experiment show that D-region variability, sporadic E, and bounds on F-region parameters can be inferred. When used in conjunction with existing ionospheric observatory data, this sensor network offers an affordable means of studying mesoscale D- and E-region weather patterns, with excellent temporal resolution (a few minutes) over entire solar cycles.

1. Introduction

The terrestrial ionosphere has been studied for decades, and much progress has been made in understanding the mechanisms and climatology of the ionosphere. The focus has been primarily on the E and F regions, since they are easily explored by remote-sensing methods, such as radars and ionosondes; the F region is also accessible to in situ satellite measurements. The E and F regions are responsible for the long-distance radio propagation that was the focus of early studies. Later studies have been motivated by the impact these regions have on space vehicles, through effects such as drag and charging.

D-region processes are less well understood. The D region forms the top of the Earth-ionosphere waveguide that defines propagation at very low frequencies ($<$ 100 kHz),

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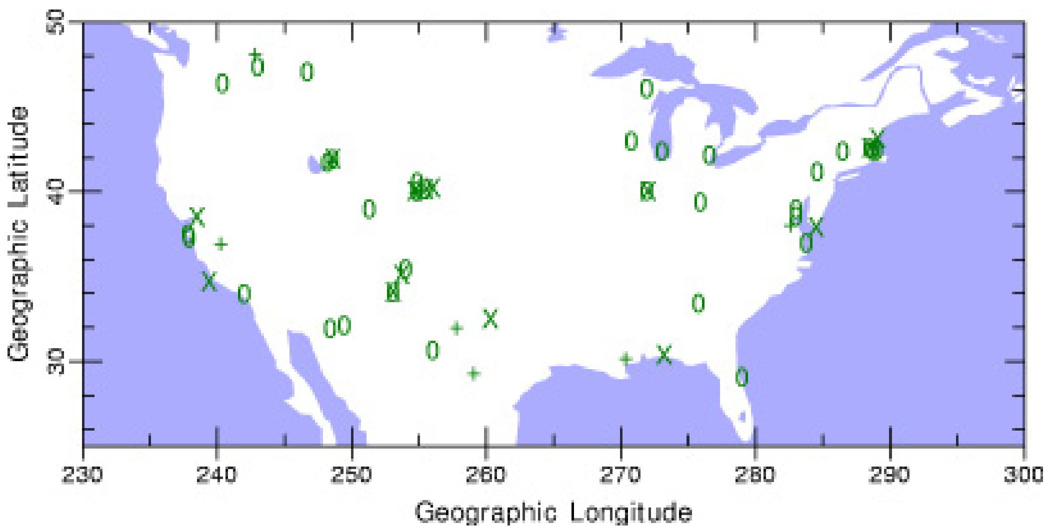

Figure 1.The distribution of magnetometers (+), optical instruments (O), and ionosondes/radars (X) in the contiguous United States from the CEDAR database.

and causes significant daytime absorption for frequencies below about 15 MHz. Few measurement techniques used for E- and F-region studies are applicable at D-region heights. Most exploration has been done with short sounding-rocket campaigns, certain satellite instruments, lidars, and specialized radars (see, for example, [1]). Mesospheric studies have provided more information about this region in recent years, but the lack of long-term, wide-area observational data hampers efforts to create realistic models.

Currently, the modeling and prediction of space-weather impacts on radio propagation are based almost entirely on statistical climatology. Mesoscale descriptions of D- and E-region responses to space weather are not available in a timely manner during the disturbances from either observations or models. Communicators need such information covering ranges of hundreds to thousands of kilometers, in order to provide effective long- and short-distance communications. This study and the proposed observation network address these needs.

The potential impacts of space weather on communications are well known. Storm effects have been described in some detail by Davies [2, Chapter 9], and Hunsucker and Hargreaves [3, Chapter 8]. Specific effects of interest in this study are:

- Sudden ionospheric disturbances (SIDs) at VLF, associated with solar X-ray flares, cause dramatic shifts in the amplitude and phase of signals used for naval communications and navigation aids [4]. At HF, X-ray flares cause strong absorption that may black out communication links for hours.
- Nitric oxide (NO) transport between high and mid-latitudes with planetary wave scales are associated with increased winter daytime D-region absorption at lower HF frequencies [5, 6], and may cause subtle VLF propagation effects.
- Sporadic E – remarkably thin, dense layers at E-region altitudes – allows signals at frequencies well above the normal maximum-usable frequency (MUF) to propagate over large distances. Generally believed to be due to wind shears [7], sporadic E may be affected by planetary waves and tides [8].

A fundamental problem with studies of space-weather phenomena is that observations are widely separated in space. Observations are often incomplete in time, with the larger instruments such as incoherent-scatter radars operating only occasionally in campaign modes. Figure 1 shows the distribution of ionospheric instrumentation in the contiguous United States, listed in the CEDAR database. Sojka et al. [9] argued that the existing observatories cannot answer long-standing questions about space-weather and upper-atmosphere dynamics, due to the inadequate spatial resolution and the irregular observing schedules. A different observing strategy is needed, similar to that employed during the International Geophysical Year (IGY), and currently used in tropospheric meteorology. Specifically, observations need to be carried out with good time resolution (minutes) for significant periods of time (years) over chains of observatories separated by a few hundred kilometers, if the spatial and temporal morphology of space-weather phenomena is to be unraveled. *This approach has been called for in the National Research Council's Decadal Research Strategy [10], and is being pursued through the Distributed Array of Small Instruments (DASI) initiative.*

Figure 2 shows an ideal distribution of observatories with 100 km north-south spacing and 300 km east-west spacing. Sojka et al. [9] argued that this spacing should be considered minimal for resolving ionospheric structures and gradients, and for achieving the desired mesoscale D- and E-region specification. This grid would require about 90 observatories. The primary hurdle in establishing such an observing grid is, of course, economics. In order to establish a large observing grid, the cost of each observatory

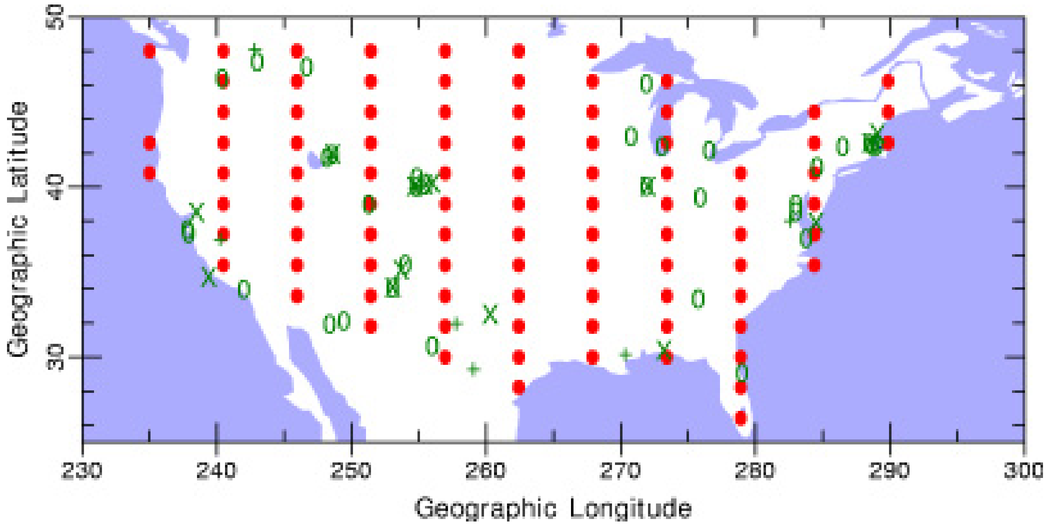

Figure 2. A minimal 100×300 km observation grid (red dots) covering the contiguous United States, compared to existing observatories (see Figure 1).

must be reasonable, and perhaps more importantly, the operating costs must be minimized. These constraints imply that each observatory must be physically small and have low maintenance, energy, and communications requirements.

One example of an extensive observation grid is the TEC (total electron content) mapping provided by dual-frequency GPS receivers. The Continuously-Operating Reference Stations (CORS) and International GNSS Service (IGS) networks provide detailed F-region information via TEC measurements. They are widely deployed across several continents, particularly in regions prone to earthquakes. The GPS instrument is relatively inexpensive, typically costing under US$20K. The networks are funded by many national agencies for various primary tasks, such as monitoring ground movements, providing accurate geolocation, and as aids to navigation. The space-weather application thus does not have to fully fund the establishment and operation of these networks.

A different approach has been demonstrated by SuomiNet (http://www.suominet.ucar.edu): rather than relying on instruments primarily dedicated to other uses, SuomiNet has established approximately 70 observatories in North America, and several on other continents, by working with schools and scientific organizations. Its observatories are small, PC-based units, with relatively sophisticated GPS receivers and meteorological sensors, which obtain various atmospheric parameters (including ionospheric TEC.) This network requires few resources, and the computer/GPS receiver can be set up in available space within existing buildings, minimizing setup costs. Local operations and maintenance (O&M) costs are minimal, since components use off-the-shelf technology. The result is a practical and cost-effective observing grid, yielding maps of TEC and meteorological quantities over wide areas with good temporal resolution.

We propose to use a similar approach to establishing observatories to map weather in the lower ionosphere. Our instrument, the Space-Weather-Aware Receiver Element (SWARE), uses software-defined radio (SDR) and a compact active antenna to monitor terrestrial beacons in the VLF through HF frequency range. Ionospheric- and propagation-modeling software is used to infer weather effects from observed signal-propagation characteristics with a temporal resolution of a few minutes. SWAREs can be set up in any location that provides computer power and Internet communications, and has low levels of radio-frequency interference (RFI). Most of the existing units are running in suburban residential environments.

Radio signal strength data from the SWARE network is collected and analyzed using comparisons to ionospheric-model and ray-tracing estimates. Data from other instruments, e.g., the low-power Canadian Advanced Digital Ionosonde (CADI) at the Bear Lake Observatory in Utah, and from other radio-propagation monitors, such as the amateur radio PropNET system (http://www.propnet.org), may also be used in the analysis. The primary products are D-region bottomside profiles and variability measurements obtained from VLF signal analysis; model D-region profiles augmented by HF absorption measurements; mesoscale sporadic E maps based on exceptional HF propagation and supported by ionogram analysis; and F-region variability measurements based on HF propagation observations compared to model estimates.

2. Passive Beacon Monitoring Revisited

Scientific studies based on passive monitoring of terrestrial radio beacons have been carried out on numerous occasions. Bixby [11] monitored the HF WWV signal (then transmitted from Washington, DC) to study HF propagation

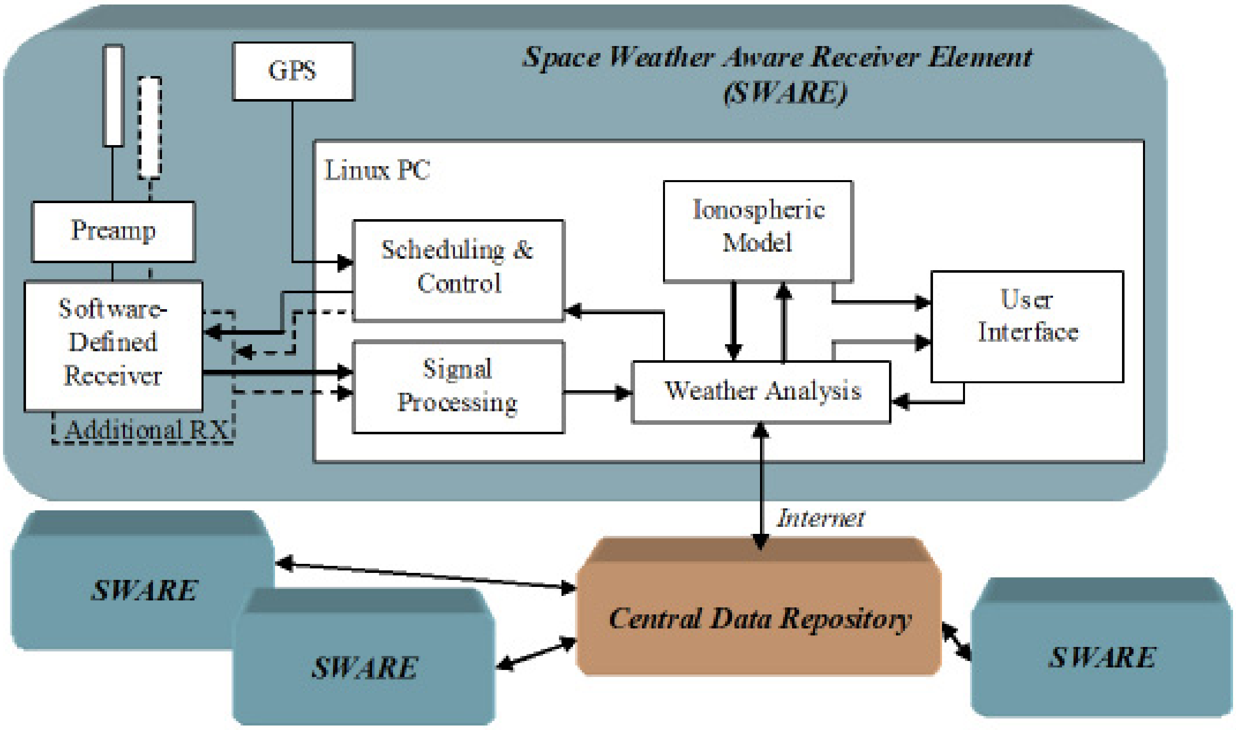

Figure 3. The Space Weather-Aware Receiver Matrix (SWARM), composed of Space Weather-Aware Receiver Elements (SWAREs) communicating with the Central Data Repository (CDR) via the Internet.

characteristics. Hunsucker [12, pp. 176-180], described oblique-incidence field-strength observations used to make absorption measurements in various frequency regimes. Definitive studies of the winter absorption anomaly were performed by Schwentek [5] using HF beacon monitoring. More recently, Navy VLF transmitters have been used as beacons to study D-region responses to solar flares and lightning (e.g., [4, 13-16]).

Traditional beacon studies have used one or a few frequencies during campaigns lasting for a few weeks or months. The limiting factor has been the interface between the radio receiver and the data acquisition and analysis equipment. Tuning to different beacons was difficult, and verifying that the received signal was due to the desired beacon and not from some other transmitter or interference generally required human oversight. These limitations are addressed by the modern software-defined-radio (SDR) receiver, which allows full computer control of all receiver functions and signal processing. Transmitters are chosen that have distinctive signals (such as the tone sequence used by WWV/WWVH) to allow the computer to determine the strength of the desired signal in the presence of noise and interference.

The Space Environment Corporation (SEC) began its passive beacon studies with the HF Investigation of D-region Ionospheric Variation Experiment (HIDIVE) and the Data Driven D-Region (DDDR) programs. Their goal was to obtain pertinent absorption data, and to ingest them to produce an improved D-region absorption model and HF propagation-prediction programs [17]. Most mid-latitude ionospheric D-region models and HF propagation-prediction programs include the solar zenith angle and the frequency-squared variation of absorption. However, the increased D-region absorption caused by specific space-weather effects, such as solar x-ray flares, changes in the neutral atmosphere, or storm-time auroral precipitation, are not included. Eccles et al. [18] described the HIDIVE and DDDR programs in detail, providing examples of ionospheric weather phenomena inferred from the HF signal observations.

The HIDIVE monitoring system implemented by Space Environment Corporation and RP Consultants began operation at the end of 2002, using an Icom R75 computer-controlled receiver to monitor all WWV/WWVH frequencies, in turn. While lacking the flexibility of the full SDR, the Icom interface was adequate to control the receiver and to acquire the signal-strength data from the receiver's automatic gain control. The audio signal was digitized and analyzed by the PC to determine relative signal-to-noise ratios. Radio monitors for the HIDIVE project were established at Bear Lake Observatory (BLO) in northern Utah; Providence, Utah (PRV); and Klamath Falls, Oregon (KFO.) These monitors demonstrated the ability of the simple HF monitor to make useful assessments of the propagation path, ionospheric absorption, and probable sporadic-E events.

New beacon monitors were designed in 2006 to cover a broader range of frequencies, and to support more-sophisticated data acquisition. The new beacon monitors

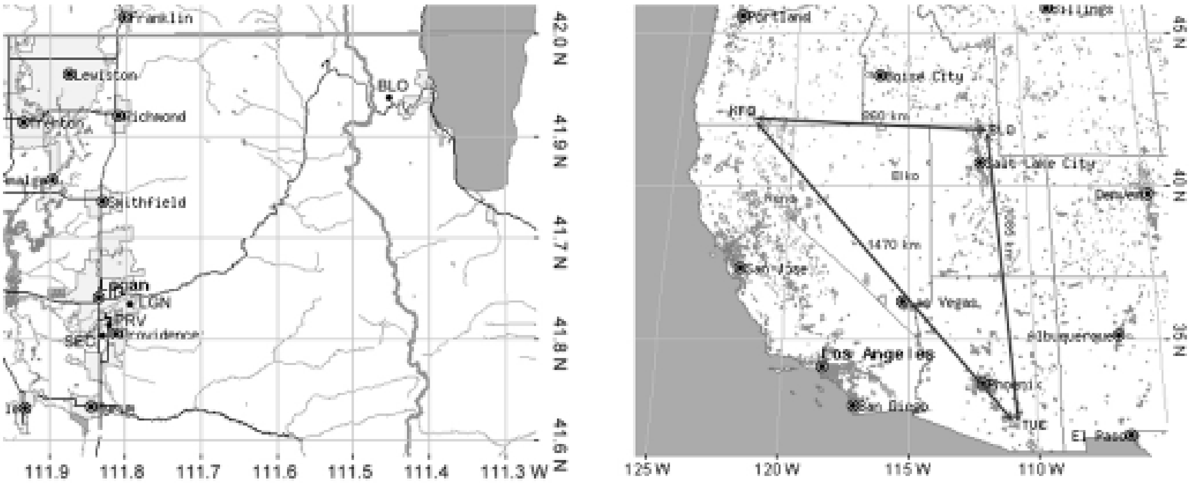

Figure 4. The initial SWARM deployment completed in November 2007, showing northern Utah (left) and the southwestern US (right). Shaded areas are populated regions. The cluster of systems in the Logan/Providence area is used for development and testing. In addition, field campaigns have been conducted at various locations in Oregon, Idaho, and Nevada.

were also given the task of performing some of the ionospheric and propagation modeling. The monitors thus became Space Weather-Aware Receiver Elements (SWAREs), and will be expected to take on more of the analysis load as the system evolves. The SWARE consists of a *Linux* PC outfitted with a winRadio G313i software-defined receiver, and a compact LF Engineering active antenna. A Garmin GPS receiver provides time and location information.

Each SWARE operates on a 15-minute duty cycle, averaging signal-strength measurements from the designated beacon transmitters, and estimating the noise in the receiver bandwidth. Each beacon signal is monitored for 10 seconds, according to a schedule that may be modified depending on conditions and observation objectives. Currently, five sets of average signal strengths are produced for each beacon in a 15-minute cycle. The SWARE also runs an ionospheric model to produce D-, E-, and F-region profiles for the area encompassing the receiver and all beacon transmitters, and performs ray-tracing through the model ionosphere for each HF signal at the 15-minute cadence. Waveguide-mode analysis of the VLF signals may also be performed. Discrepancies between observations and model analysis may indicate space-weather effects, as discussed in Sections 4 and 5.

The network of SWAREs is the Space-Weather-Aware Receiver Matrix (SWARM), depicted in Figure 3. A Central Data Repository (CDR), located at SEC, collects observations of beacon signal strength from the individual SWAREs, and also distributes geophysical indices, updates, and directives to the remote units.

The current SWARM deployment is shown in Figure 4. The three primary sites are at the Bear Lake Observatory (BLO) in northern Utah; Klamath Falls (KFO), Oregon, maintained by Dr. Robert Hunsucker; and Tucson (TUC), Arizona, maintained by Dr. John Raitt. These three locations form a triangle with an 860 km east-west alignment between BLO-KFO, and a 1,085 km north-south alignment between BLO-TUC. The baselines then provide the outer spatial mapping scale, 1,000 km, for the SWARM to study 10 to 1,000 km ionospheric structures.

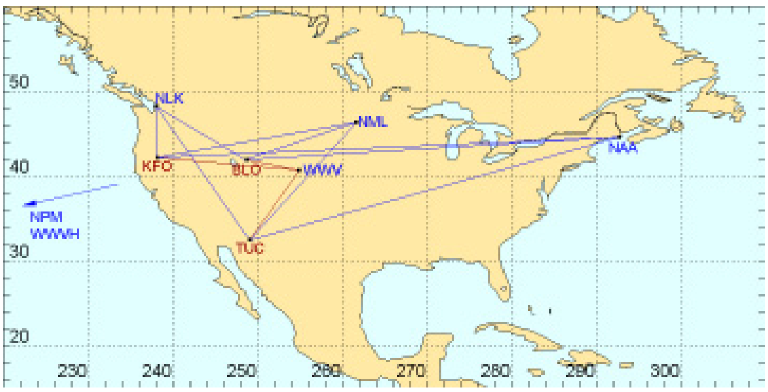

Figure 5. The primary transmitter/receiver paths that are currently monitored. NPM and WWVH are in Hawaii.

Additional SWAREs have been deployed at other locations. Initial development sites were in River Heights (PRV), Utah; Providence (SEC), Utah; and in Logan (LGN), Utah. The separation distance between these three is less than 10 km, and the group lies about 40 km southwest of BLO. Currently, these SWAREs are being used in field-observation campaigns, lasting from a few days to a few months, at various locations in Idaho, Oregon, Nevada, and Montana. Deployments in western Canada are anticipated in 2009.

The primary VLF transmitters for the western United States are NML (25.2 kHz) in La Moure, North Dakota, and NLK (24.8 kHz) in Jim Creek, Washington, with relatively short transmitter-receiver paths. Longer paths to NAA (24.0 kHz) in Cutler, Maine, and NPM (21.4 kHz) in Lualualei, Hawaii, are also monitored, since they may help characterize large-scale phenomena. The paths are shown in Figure 5. Two HF transmitters – WWV in Ft. Collins, Colorado, and WWVH in Kekaha, Hawaii – are also monitored, continuing the HIDIVE observations. WWV and WWVH operate at 2.5, 5, 10, and 15 MHz; WWV also transmits on 20 MHz.

Plans call for the expansion of the number of transmitters being monitored as the acquisition and analysis software evolves. The number of signals available in the VLF range is limited, but there are a large number of potential LF beacons. The LF time-standard station WWVB (60 kHz) at Ft. Collins, Colorado, has recently been added to the monitoring sequence. Numerous aeronautical beacons operating in North America will be exploited to provide useful information about conditions in the lower ionosphere between dusk and dawn. At HF, amateur-radio beacons are

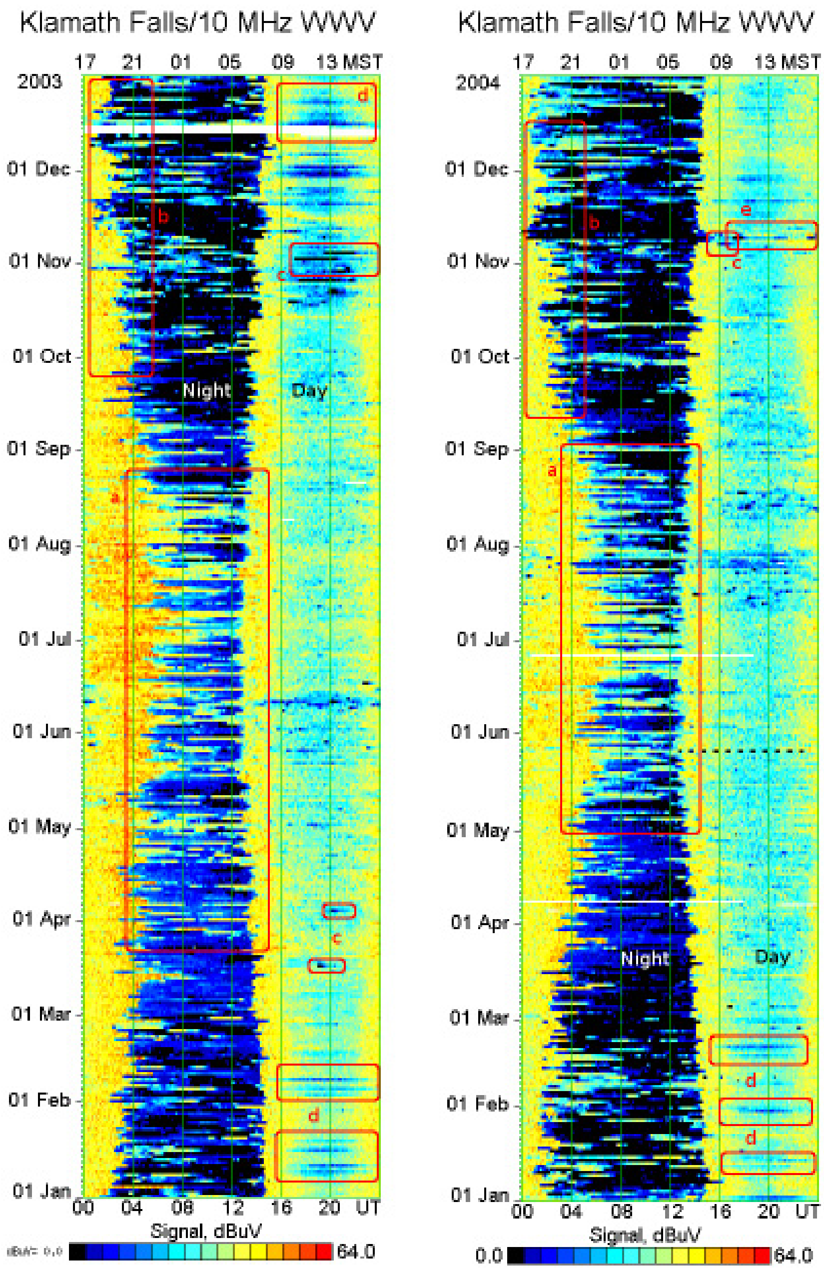

Figure 6. A comparison of the HF WWV 10 MHz signal received in Klamath Falls, Oregon, during 2003 (left) and 2004 (right.) The dark region in the center is night, when the MUF drops below 10 MHz for this path. Labels mark weather phenomena (see text).

the major source of widely-distributed transmitters. Extensive beacon networks already exist to allow amateurs to identify and exploit sporadic-E occurrences [19, 20]. Some HF amateur-radio observations are currently included in SWARE analyses.

3. Weather in the Lower Ionosphere

This study focuses on weather effects in the lower ionosphere, below about 150 km. Daytime electron density in this region ranges from about 10^5 electrons per cm^{-3} in the E region, to less than 100 per cm^{-3} at the bottom of the D region. During quiet conditions, the electron density of the lower ionosphere changes by at least two orders of magnitude over 24 hours. The best-known weather effect in this region is sporadic E, typically in the 90-120 km height range. This strongly reflects radio waves in the HF spectrum, and can provide over-the-horizon reflections up to about 100 MHz. However, there are also strong quasi-periodic variations in the D region, which cause variable daytime absorption of radio waves in the lower HF range. The D-region bottomside also controls VLF propagation, and even at night there is sufficient ionization below the E region to affect VLF. Thus, studies of VLF and HF signals can provide information about D-region variations, and HF signals may provide information about sporadic E.

Data collected by HIDIVE show numerous effects of D-, E-, and F-region weather, with observations spanning major space-weather storms. Figure 6 shows the signal strength on the WWV-KFO 10 MHz path for 2003-2004. White lines are missing data due to system downtime; the completeness of the data set demonstrates the reliability of the beacon-monitor hardware. The dark band in the middle of each panel is local night, when the maximum usable frequency of the path drops below 10 MHz. The left edge of the dark band is dusk, and the right edge is dawn. Notable weather effects are summarized below.

1. During summer, there is frequent propagation at night due to sporadic E. The presence of sporadic E on the WWV-KFO path is often confirmed by the CADI ionosonde, operated by SEC at Bear Lake Observatory, which is near the midpoint of the WWV-KFO path.
2. Major solar activity occurred late in both 2003 (the Halloween storm) and 2004. During these times, the dusk line was modulated with a 27-day period, corresponding to increases in F10.7 as the most active regions of the sun rotated into view.
3. Daytime short dark features that were black fading to gray (left-to-right) were solar X-ray flare absorption events. Examples of moderate flares were at 1900 UT on 17 March 2003, and 2000 UT on 4 April 2003. Large flares occurred at 2100 UT on 29 October 2003, 1800 UT on 2 November 2003, and 1600 UT on 7 November 2004.

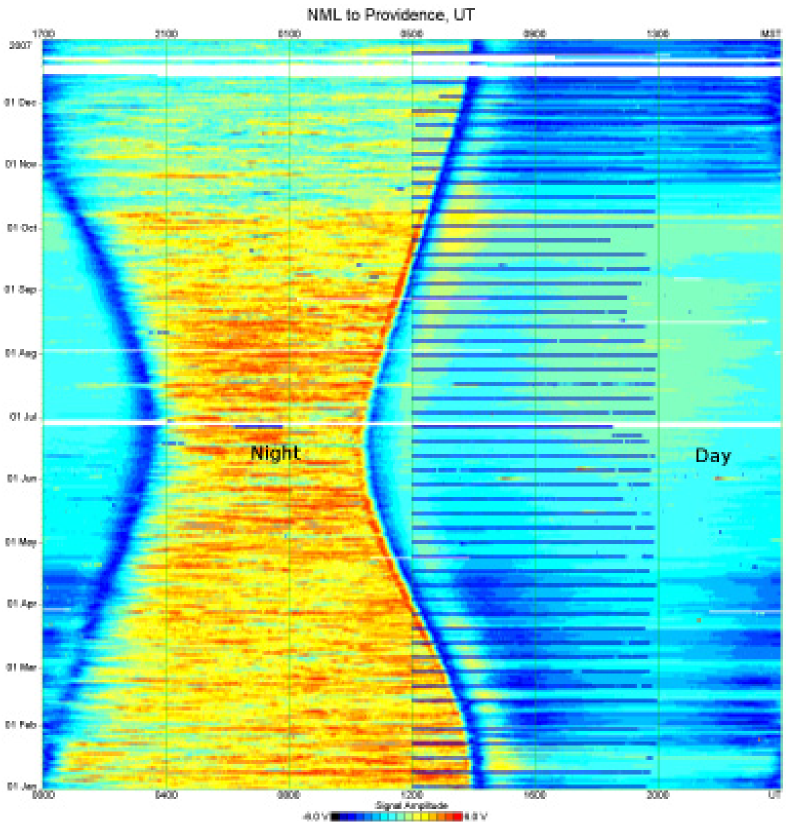

Figure 7. VLF signal strength observations for 2007 from the Stanford NML receiver (25.2 kHz) in Providence, Utah. Signal levels were typically higher and more variable at night than during the day.

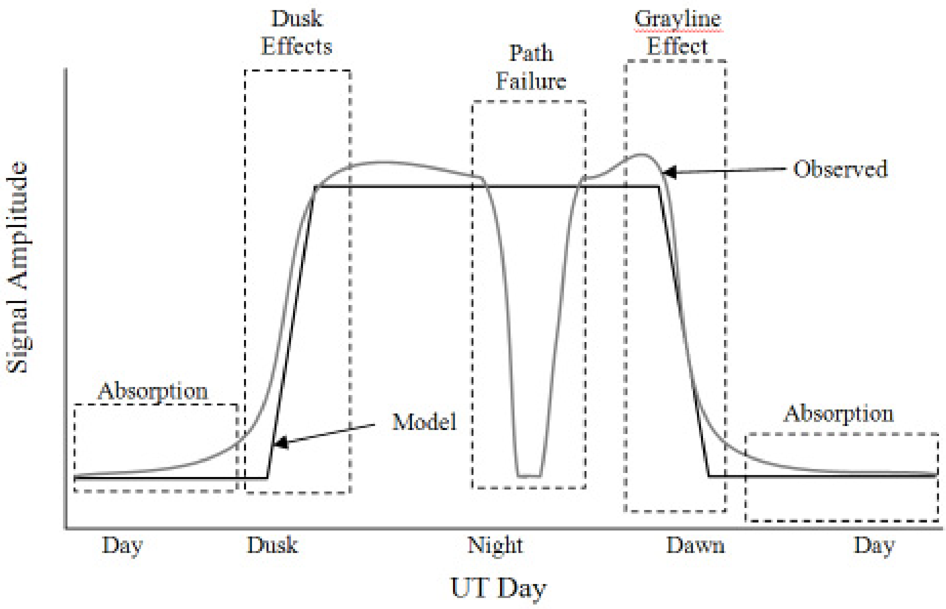

Figure 8. Low-HF propagation modeling and analysis. The daytime signal is completely absorbed and provides little information. The dusk-signal increase shows the complex interaction of D- and E-region decay and F-region lifting. At night, the power spectrum may reveal gravity-wave activity; a sharp drop indicates a path failure, either due to inadequate foF2 or sporadic E blocking the path. A dawn grayline signal enhancement is often observed before absorption eradicates the signal.

4. Daytime dark regions that lasted for more than one day were often winter-absorption anomalies. The anomalies were identified by a solar-zenith-angle dependence in the signal level, as shown below. Severe absorption was seen in early December 2003. Milder absorption anomalies could be seen in early January and February in both 2003 and 2004.
5. Other instances of low daytime signal (e.g., 10 November 2004) were associated with ionospheric storms that caused large fluctuations in F-region densities, and lowered the MUF below 10 MHz.

Some limitations in characterizing the D region by means of HF propagation analysis may be addressed by examining VLF propagation. For example, the nighttime D and E regions (other than sporadic E) have no significant effect on HF signals, but VLF is sensitive to the low nighttime densities at those heights. Another HF limitation is seen during large X-ray flares, where the normal daytime HF signals may be completely absorbed, while VLF signals change in interesting and sometimes complex ways.

VLF data collection began in conjunction with Stanford University's Sudden Ionospheric Disturbance (SID) project for the International Heliospheric Year (IHY), using dedicated single-frequency receivers with loop antennas. The complete 2007 VLF data set of the NML-to-Providence (PRV) path, obtained from the Stanford SID receiver, is shown in Figure 7. The very distinctive hourglass shape was due to the seasonal variation of daylight hours, similar to the dark region in Figure 6. The area inside the hourglass shape was nighttime, where maximum signal levels were usually observed for this path, and the narrowest section of the hourglass was summer solstice. The series of regularly-spaced black horizontal stripes between 1200 and approximately 2000 UT represented once-per-week maintenance outages of the NML transmitter. White areas were missing data, caused by failures at the receiver site. For this path, solar X-ray flares produced enhanced signals: three moderate flares could be seen in early June after 1400 UT, appearing as light streaks.

While the analysis of the HF signal depends primarily on the ability of the ionosphere to reflect or absorb the signal at a given time, the VLF signal strength depends on the interference between modes in the earth-ionosphere waveguide. For the NML-PRV path, analysis indicated a well-defined signal-strength minimum associated with an effective height of $H' \sim 84$ km. Daytime H' values were ~72 km, and nighttime values were ~90 km. Thus, at dawn and dusk, H' passed through the minimum-signal region, producing the sharp border of the hourglass shape. The dawn crossing (right side) was sharper than the dusk crossing, and was sharpest in summer. This behavior was consistent with the solar zenith angle changing more rapidly during summer dawn than during winter dawn. The dusk crossing was indistinct at times during the winter, suggesting that the vertical gradients at dusk prevented the significant signal minimum from occurring.

Some seasonal effects in Figure 7 had less-obvious causes. Daytime signal levels increased abruptly in mid-April and decreased again in October. A gradual shift between winter and summer signal levels was expected due to higher summer sun angles, but the abrupt change suggested another cause, such as a seasonal change in mesospheric wind patterns. The nighttime signal levels reached much higher levels in the summer, but also had much greater

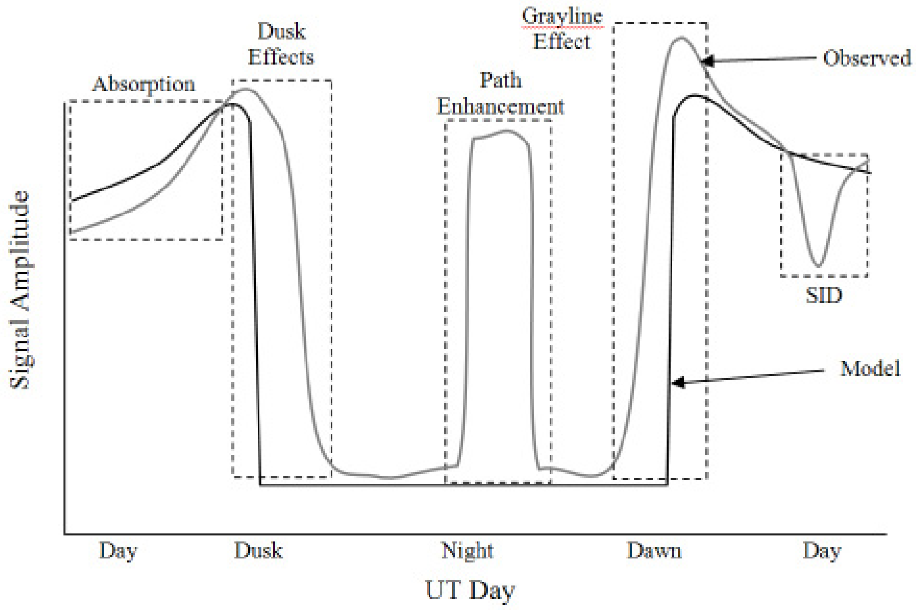

Figure 9. Mid-HF propagation modeling and analysis. The daytime signal is absorbed as a function of solar zenith angle and D-region NO concentration. At night, the signal exceeds the MUF, and propagation ceases. Occasionally, a path enhancement enables nighttime propagation. A dawn grayline enhancement is often seen. Solar flares increase D-region absorption and produce an HF SID signature.

variability, with nighttime signals erratically dropping below daytime levels. The greater summertime variability could be due to H′ being lower in summer than in winter, near the very sensitive range of H′~84 km, where the signal strength minimum occurred on the NML-PRV path. For a summer H′~ 87 km,, vertical motions due to winds and waves would produce larger signal variations than for a winter H′ of 90 km.

The behavior shown in Figure 7 was specific to the NML-PRV path. The seasonal behavior was actually quite similar in the NLK-PRV data, which had a similar path length. However, diurnal signal changes in KFO and TUC data were very different, due to differing Earth-ionosphere waveguide lengths and geometries. For example, the NLK-KFO data had a strong signal enhancement at dawn and dusk rather than a minimum, while NML-KFO, NML-TUC, and NLK-TUC paths had very subtle changes in signal levels at dawn and dusk.

4. HF Signal Data Analysis

Weather effects are inferred by comparison of measured signal levels to expected signal curves. For HF, the expected signal curve is derived from ray tracing through

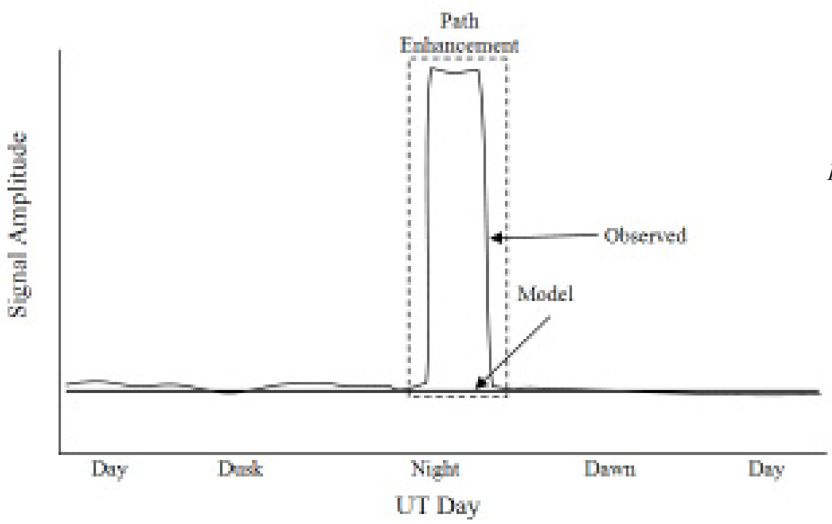

Figure 10. High-HF propagation modeling and analysis. The signal exceeds the MUF day and night. Propagation occurs occasionally due to a path enhancement, such as sporadic E.

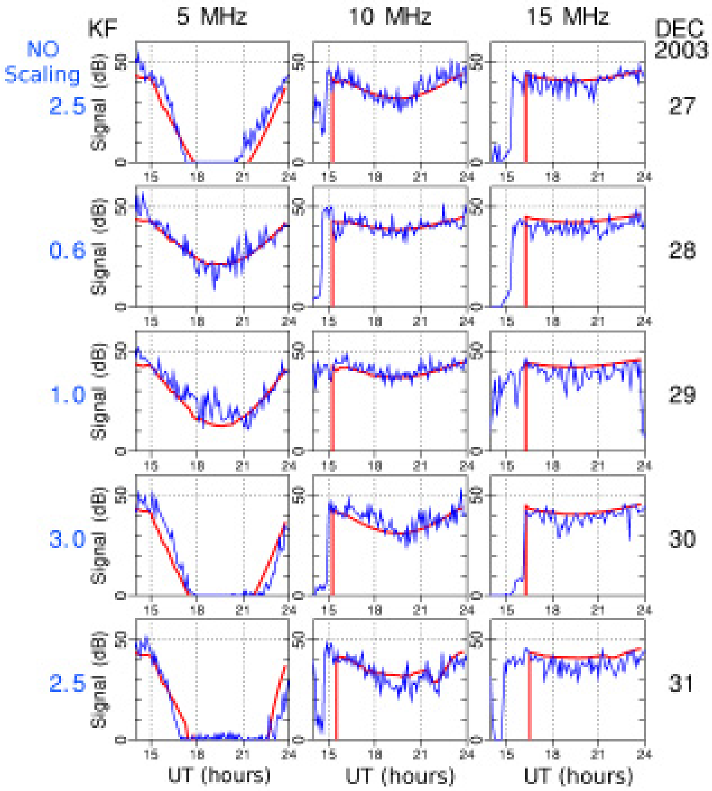

Figure 11. The KFO signal strength at 5, 10, and 15 MHz for December 27 through 31, 2003. The solid lines are the observed signal strength, while the dashed lines are the DDDR simulations based on scaled NO profiles, the scaling factors for which are listed at the left of each 5 MHz panel.

a model ionosphere. The median signal for the past week is used to establish the typical range of signal amplitudes.

The model ionosphere is produced by blending a D-region model (DDDR) with E- and F-region model results. The DDDR model is a simple ion-chemistry model of the D region, designed to incorporate sufficient positive and negative ion chemistry to generate an appropriate electron density for a wide range of natural geophysical conditions. Presently, the D-region model contains sufficient physics and chemistry to provide an electron density profile from 40 to 110 km altitudes for mid- and low-latitude HF propagation paths. The D-region model uses geophysical data streams available at NOAA, which provide real-time input into the space-weather events that affect D-region densities. The E and F regions may be modeled by a standard code such as IRI [21]. The results are combined to provide a complete electron-density specification for HF propagation and absorption calculations. The ray tracing is achieved using Dr. C. Coleman's HASEL ray-tracing program [22], modified to calculate path absorption.

HF paths for HIDIVE and SWARM are chosen so that single-hop E and F propagation is probable, and the signal behavior may be described by one of the following three cases.

First, low-HF paths have frequencies well below the typical MUF, generally below 10 MHz. As shown in Figure 8, the expected signal curve has strong nighttime propagation, but daytime signals are strongly absorbed. Weather effects are thus limited to dusk through dawn, and are largely controlled by F-region behavior. Periodic fades due to atmospheric waves are common, but at times path failure occurs. Path failure may be due to the MUF falling below the signal frequency, or due to sporadic E blocking the primary propagation path.

Second, mid-HF paths have frequencies below the daytime MUF, but above the nighttime MUF (Figure 9.) Measuring the depth of daytime absorption relative to the expected signal curve provides an estimate of D-region density variation. Sharp departures from the expected signal curve may indicate solar-flare absorption events. At night, a well-defined path enhancement may be due to an unexpected MUF increase or to sporadic-E propagation. A dawn enhancement is often observed, and propagation may resume somewhat earlier than the expected signal curve indicates, due to focusing effects.

Third, high-HF paths have frequencies well above the MUF, generally above 15 MHz. In this case, the expected signal curve is always at the noise floor (Figure 10.) If the signal frequency is sufficiently above the MUF, path enhancements are generally assumed to be due to sporadic E.

The primary phenomena of interest for mapping are sporadic E and absorption. Sporadic E may be inferred from path enhancements in nighttime mid-HF paths and all high-HF paths when MUF variations are judged inadequate to produce the path enhancement. Absorption is obtained from daytime mid-HF paths.

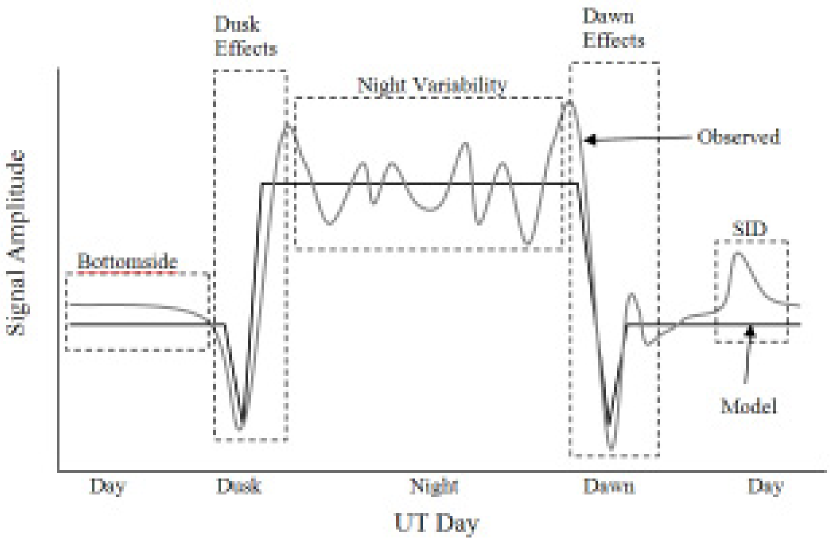

Figure 12. VLF propagation modeling and analysis. The daytime signal provides the D-region bottomside profile (left), while SID signature detection (right) allows the D-region enhancement from a solar flare to be estimated. Dawn and dusk effects allow the rate of change of the D-region profile to be quantified. Dawn often includes focusing that is not well modeled. At night, variability (average, standard deviation, power spectrum) indicates the level of atmospheric disturbance (winds and waves) at about 90 km.

Figure 11 shows an example of winter absorption changes observed by HIDIVE on a mid-HF path in December 2003, and analyzed with DDDR. For the multiple daytime scale shown, the D-region variability responsible for the changes in absorption was thought to be associated with redistribution of the mesospheric NO via planetary waves [6]. The changes in absorption were thus addressed by changing the NO concentration in the D-region model.

Large day-to-day variability of 5, 10, and 15 MHz WWV signals received at Klamath Falls was observed from December 27 to 31, 2003. The effect was most noticeable on the 5 MHz signal. Signal strength on December 27, 30, and 31 fell too low to be detected at noon (around 1900 UT), while on December 28 and 29, the absorption was at least 20 dB less. In order to model these differences, the NO level for each day was scaled. On the three strong absorption

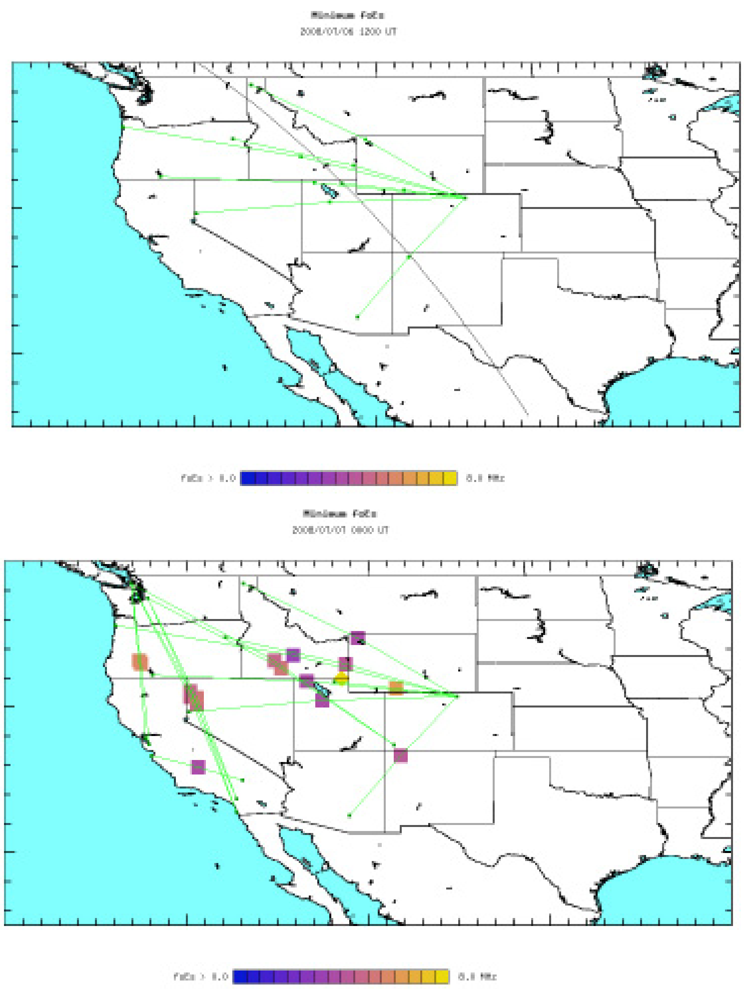

Figure 13. Sporadic-E minimum densities mapped during July 2008. No sporadic E was detected at 1200 UT on 6 July 2008 (top), but twelve hours later, sporadic E was present across the western US (bottom). The curved line in the top map was the dawn terminator. SWARE HF paths originated with WWV in Ft. Collins, CO. Other paths involved amateur-radio HF beacons.

days, factors of 2.5, 3.0, and 2.5 were needed on December 27, 30, and 31, respectively. On December 28, a reduction in NO was required, i.e., a factor of 0.6. The same factors were used for 10 and 15 MHz. The NO factor on various paths may be used to develop a map of D-region variations.

5. VLF Signal Data Analysis

At VLF, an expected signal curve is developed based on a different modeling strategy. Instead of ray tracing, the appropriate propagation model for these longer wavelengths is a waveguide defined by the Earth below, and bounded above by the D region. This analysis is performed by the US Navy's Long Wave Propagation Capability (LWPC) [23], which has been used for many other scientific studies. An exponential ionosphere defined by effective height and slope parameters is used to describe the bottom of the D region, in conjunction with DDDR for LWPC. The median signal level of the past week is used to set the range of signal levels.

The shape of the expected signal curve varies dramatically with the path. Figure 12 shows a curve typical of NLK or NML received in northern Utah. During the day, variations from the expected signal allowed the exponential bottomside parameters to be adjusted; these changes were typically small. More dramatic changes were inferred from SID signatures, when the bottomside effective height dropped significantly and the D-region density increased. At night, the variability of the signal is quantified by the mean and standard deviation, and atmospheric wave activity is quantified by power spectra. The rate of change of dawn and dusk signals is used to determine the change in the D-region effective height.

The VLF analysis thus far has led to modifications of the D-region model's nighttime chemistry, as well as preliminary inversions of X-ray flare SIDs and winter-anomaly enhancements.

6. Data Mapping

When multiple-sensor observations are combined, information about the spatial characteristics of the ionosphere may be deduced. In Figure 13, the minimum sporadic-E critical frequency required to provide observed HF propagation was mapped for two times in the western United States. Observations included SWARE 20 MHz WWV signal strength, ionograms from the Bear Lake Observatory in Utah, and HF amateur-radio beacon-signal observations. In the first instance (top panel), no sporadic-E propagation was observed for any monitored path. Sporadic-E observations increased during the next twelve hours, until it was observed on most of the monitored paths (bottom panel.)

The maps produced by the prototype network, though sparse, have demonstrated the complexity of the sporadic-E phenomenon summarized by Whitehead [7]. During the summer, sporadic E was observed to appear almost simultaneously across the monitored paths in the western United States, "blooming" in a manner reminiscent of summer thunderstorms on weather maps. A few instances were found where sporadic E appeared to travel across the mapped area: on 4 July 2008, sporadic-E propagation spread westward with an apparent motion of 68 m/s. Some sporadic-E maps indicated broad bands with northern and southern boundaries, while others showed clouds limited in both latitude and longitude. During the summer, regular morning and evening sporadic-E events were noted, similar to the semi-diurnal tide effects described by Mathews [24]. A prolonged series of sporadic-E events were observed in late 2008 with a regular 24-hour pattern.

Currently, efforts are being made to map D-region variations related to the winter-absorption anomaly. These events have been less dramatic during the period of SWARE operation, due to the unusually-quiet solar-minimum conditions. However, there is some indication of connections between daytime D-region absorption at HF and nighttime VLF signal fluctuations suggestive of an equator-ward drift. More observations of these effects are needed.

7. Conclusion

The Space Weather-Aware Receiver Element (SWARE) has been designed to monitor ionospheric conditions and signal-propagation characteristics with good time resolution (<15 minutes) and minimal cost. Affordability includes not only the initial cost of the instrument, but also the small footprint, high reliability, and low operation and maintenance costs.

The SWARE provides real-time raw signal and initial model results to the local operator. When combined with other units to form a Space Weather-Aware Receiver Matrix (SWARM), the results can be turned into a geographical map of the observed and modeled parameters covering thousands of kilometers, with resolution on the order of 100 km. Observations from other instruments and observation networks may be ingested into the mapping process. The comparison of observations at the Central Data Repository (CDR) also allows for better quality control, isolating anomalies that may be due to local interference or equipment failures. The current development emphasis of the signal data analysis is to create the following products:

- D-region structure specification in latitude and longitude, including the absolute density profile from the Data-Driven D-Region model. This will improve HF radiowave absorption determination, as well as defining the upper boundary conductivities for waveguide propagation calculations below 1 MHz.

- E-region structure specification in latitude and longitude, with a particular emphasis on sporadic-E conditions for operational users and scientific studies. The primary goal is to map the mesoscale spatial distribution of sporadic E, setting bounds on the sporadic layer density.

- F-region variation specification in latitude and longitude through modeling with observational bounds on the profile's peak density.

Efforts are underway to improve observations with additional SWARE sites in the western United States and Canada. Data acquisition, modeling, and analysis software are evolving steadily, with current data and analysis results available at http://www.spacenv.com/~agile.

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Coherent Radar Measurements of the Doppler Velocity in the Auroral E Region

R.A. Makarevich

Abstract

This review surveys new evidence derived from Doppler velocity measurements by HF and VHF coherent radars in the auroral E region. We focus on the E-region Doppler velocity dependence on the three-dimensional plasma-convection velocity. The knowledge of this dependence is critical to our understanding of the fundamental physics of weakly ionized plasma, as well as to developing an ability to derive plasma-convection velocities from E-region coherent radar echoes. We critically examine the potential of the linear fluid theory of the E-region plasma irregularities in interpreting the Doppler velocity observations, in view of the recent developments in application of the theory that included the ion-motion effects and non-orthogonality of backscatter.

1. Introduction

Ionospheric plasma irregularities have attracted a significant research effort over the last five decades. They provide important information on the physics of weakly ionized plasma, as well as on the global plasma convection and related processes in the Earth's ionosphere. Plasma irregularities are also known to adversely affect radio and satellite communication systems, especially during significant geomagnetic disturbances, i.e., space-weather events.

Radar echoes from auroral irregularities, also referred to as the radar aurora, have traditionally been under investigation, since they are routinely detected with coherent Doppler radars operating at UHF, VHF, and HF frequencies.

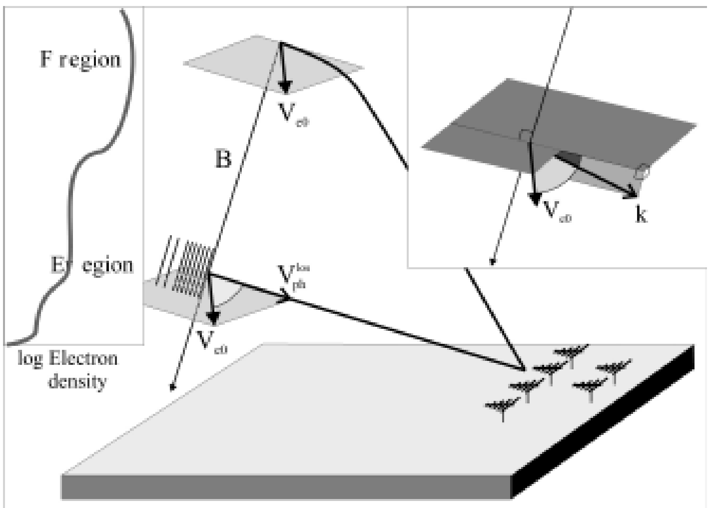

*Figure 1. Coherent radar measurements in the auroral ionosphere. The top-left corner insert shows the idealized electron-density profile in the ionosphere with the E and F ionospheric regions indicated. The center schematic shows the main (left) and interferometer (right) antenna arrays, the two ray paths reaching orthogonality with the inclined magnetic field line **B** in the E and F regions, the field-aligned wavefronts in the E region, and the magnetic-field-perpendicular planes in the E and F regions. Also shown are the electron drift velocity vectors* $\mathbf{V}_{e0}$ *in the E and F regions, the line-of-sight irregularity phase velocity* V_{ph}^{los}*, and the flow angle,* θ*, between the irregularity propagation vector,* ***k****, and* $\mathbf{V}_{e0}$*. The top-right insert also shows the aspect angle,* α*.*

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Figure 1 shows the principle of coherent radar measurements. The idealized electron-density profile is shown on the left, as well as the two layers of ionization near 110 km and above 150 km, known as the E and F regions, respectively.

The irregularities have been shown to be strongly magnetic-field aligned, due to high mobility of electrons along the magnetic field. The wavefronts interfere constructively only with fronts separated by half of the radar wavelength, due to the Bragg condition, $\lambda_{irr} = \lambda_{rad}/2$. The coherent echo power is strongly peaked at the magnetic-field-perpendicular plane. Consequently, the radar beam needs to reach orthogonality with the local magnetic-field line (the orthogonality condition) for a radar to detect echoes at a given location. The auroral radars hence typically sample high-latitude regions from lower latitudes.

This is illustrated in Figure 1, which shows a typical geometry for auroral radar observations with two radar ray paths. The lower straight beam reaches orthogonality with the magnetic field, **B**, in the E region, where the wavefronts shown by the short magnetic-field-aligned lines propagate in the field-perpendicular plane. The straight-line propagation implies no refraction due to the ionospheric electron density, which is a good approximation at UHF and VHF, where the frequency is too large for appreciable refraction. On the other hand, the HF radars (3 to 30 MHz) experience some refraction, so that the orthogonality condition can be met earlier along the radar ray path or, in the case of an antenna pattern sufficiently wide in the vertical direction, even in the F region. The F-region backscatter is illustrated by the upper ray path that is curved to reach orthogonality at higher altitudes. Even though in Figure 1 the orthogonality is reached on the same magnetic-field line, more often the F-region backscatter occurs farther away from the radar site than the E-region echoes.

Most radars measure the echo Doppler shifts, which are proportional to the radar frequency. The Doppler velocity is typically obtained by dividing by the frequency, to make easier comparisons between radars operating at different frequencies. The measured Doppler velocity corresponds directly to the line-of-sight (los or l-o-s) component of the irregularity phase velocity, V_{ph}^{los} (Figure 1). The bulk

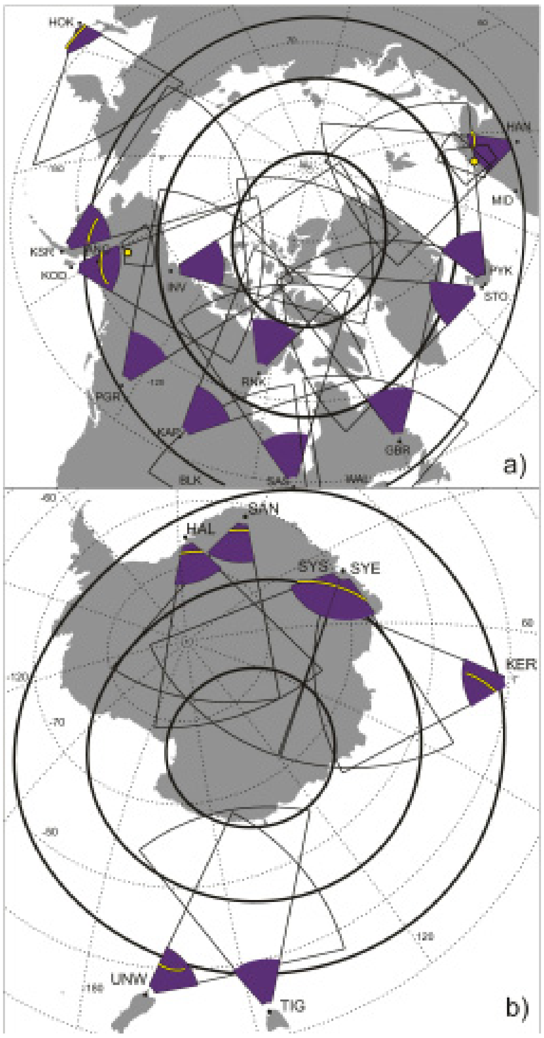

Figure 2. Coherent radars in the (a) northern and (b) southern hemispheres. The SuperDARN HF radar locations and near fields-of-view (range 180-765 km) corresponding to the E-region backscatter are shown by the black dots and blue sectors, respectively. The standard three-letter notations for the radars are shown near the radar sites. The STARE VHF radars in Scandinavia (operational until May 2005) and the VHF radar imager in Anchorage, Alaska, are also shown in panel (a). The locations of the PFISR and EISCAT incoherent scatter radars in Poker Flat and Tromsø are shown by the yellow circles. The heavy black curves are the lines of equal magnetic latitude or L shells, $\Lambda = 60°$, 70°, and 80°. The heavy yellow curves represent the lines of zero geometric aspect angle, $\alpha = 0$, at 110 km.

plasma-convection velocity in the E region is approximately the same as the background electron-drift velocity, $\mathbf{V}_{e0}$, because ion-drift motions are controlled by the frequent collisions with the more abundant neutral particles and are relatively slow. However, attempts to establish the relationship between the plasma-convection velocity, $\mathbf{V}_{e0}$, and the E-region irregularity phase velocity, V_{ph}, have been only partially successful. This is despite the relationship's fundamental importance, and a wide range of possible applications involving estimates of the plasma drift velocity , $\mathbf{V}_{e0}$, in extended areas of the high-latitude ionosphere.

In the F region, it is generally accepted that $V_{ph} = V_{e0} \cos\theta$, where the flow angle, θ, is an angle between the plasma flow and the wave-propagation vector. The importance of the plasma-velocity estimates is evidenced by the success of the Super Dual Auroral Radar Network (SuperDARN) of coherent HF radars [1]. The SuperDARN radars measure the line-of-sight velocity of the F-region irregularities, V_{ph}^{los}, from which two-dimensional plasma-convection velocities, $\mathbf{V}_{e0}$, can be estimated. Figure 2 shows the locations and footprints of various radars, including 19 coherent HF radars comprising SuperDARN for the (a) northern and (b) southern hemispheres.

In Figure 2, the standard three-letter notations are used, with (from westernmost radar counterclockwise) Hokkaido (HOK), King Salmon (KSR), Kodiak (KOD), Inuvik (INV), Prince George (PGR), Kapuskasing (KAP), Rankin Inlet (RNK), Blackstone (BLK), Saskatoon (SAS), Wallops Island (WAL), Goose Bay (GBR), Stokkseyri (STO), Pykkvibaer (PYK), and Hankasalmi (HAN) radars shown in panel (a). Panel (b) shows the TIGER Unwin (UNW), TIGER Bruny Island (TIG), Kerguelen (KER), Syowa East (SYE), Syowa South (SYS), Sanae (SAN), and Halley (HAL) radars. The radar footprints mostly cover the auroral zones in both hemispheres (located roughly between magnetic latitudes of 60° and 80°, represented by the outer and inner heavy ovals). More recently installed SuperDARN radars also cover the northern polar cap (roughly pole-ward of 80°N: RNK, INV), as well as the mid- and sub-auroral latitudes (equator-ward of 60°: WAL, HOK, BLK).

In the E region, the irregularity phase velocity has been shown to behave differently with the flow angle [2]. The velocity has also been shown to depend on the aspect angle, α, between the wave-propagation vector, $\mathbf{k}$, and the field-perpendicular plane [3-5] shown in the top-right insert in Figure 1. The large differences between the results obtained using radars at various locations and frequencies, as well as considerable difficulties in obtaining information on the flow and aspect angles, made it very difficult to develop methods to estimate $\mathbf{V}_{e0}$ based on the E-region observations of irregularity velocity V_{ph}.

Figure 2 also shows the nominal SuperDARN radar footprints in the E region by blue sectors (the first 13 range gates in the normal mode, 180-765 km). The yellow curves within the E-region footprints are the lines of zero (if achievable) geometrical or rectilinear aspect angle at 110 km (see Section 3.4). The E-region echo occurrence and power are expected to maximize near these locations in the absence of ionospheric refraction. Despite much smaller size as compared to the F-region footprints, the number of echoes that can be detected at these ranges is quite considerable (13 out of a total of 70 range gates, or $\sim 20\%$). If utilized properly, they can effectively extend the SuperDARN viewing area towards sub-auroral latitudes. This region is critical to our understanding of the plasma dynamics during geomagnetic disturbances, when the auroral oval expands equator-ward, often moving outside of the SuperDARN viewing area in the F region.

The aim of this paper is to review recent observations of the E-region irregularity velocity, focusing on its relationship with the plasma drift velocity. We survey comparisons of the coherent Doppler radar measurements with the F-region plasma drift velocities measured using incoherent-scatter radars, sounding rockets, and low-orbit satellites, as well as simultaneous HF radar measurements of E- and F-region velocities. We summarize and contrast different models supported by observations, in particular critically examining the potential of the linear fluid theory of the E-region irregularities in explaining observations.

Several reviews have surveyed observations and theories of the radar aurora [6-11]. This review encompasses the period since 2002, and aims at a reader not necessarily familiar with the field. Section 2 summarizes theoretical predictions on the flow and aspect-angle dependencies, while Section 3 resurveys experimental techniques. Sections 4 and 5 review recent studies on the flow and aspect-angle dependencies, respectively. Finally, suggestions for future research and major conclusions are presented in Sections 7 and 8, respectively.

2. E-region Irregularity Theory

The idea that the E-region plasma waves observed by coherent radars are caused by the modified (by the magnetic field) two-stream or Farley-Buneman plasma instability (MTSI or FBI) in the central part of the E region (105-110 km) was independently formulated by [12] and [13]. The linear fluid theory of the FBI, in which the fluid continuity and momentum equations are considered for electrons and ions, was able to reproduce many of the irregularity properties observed experimentally, for example, the magnetic-field-aligned nature of these irregularities.

In this approach, the phase velocity, V_{ph}, and growth rate, γ, of the unstable waves in the rest frame of the neutrals are given by

$$V_{ph} = \hat{\mathbf{k}} \bullet \frac{\mathbf{V}_{e0} + \Psi \mathbf{V}_{i0}}{1+\Psi} = \frac{V_d \cos\theta}{1+\Psi} + \hat{\mathbf{k}} \bullet \mathbf{V}_{i0} , \qquad (1)$$

$$\gamma = \frac{\Psi}{1+\Psi}\frac{k^2}{\nu_i}\left[\left(V_{ph} - \hat{\mathbf{k}} \bullet \mathbf{V}_{i0}\right)^2 - C_s^2\right], \qquad (2)$$

where

$$\Psi = \frac{\nu_e \nu_i}{\Omega_e \Omega_i}\left(\cos^2\alpha + \frac{\Omega_e^2}{\nu_e^2}\sin^2\alpha\right) \qquad (3)$$

is the anisotropy factor; $\hat{\mathbf{k}} \equiv \mathbf{k}/k$ is the unit vector along the irregularity propagation vector **k**; $\nu_e\left(\nu_i\right)$ and $\Omega_e\left(\Omega_i\right)$ are the collision frequency with neutrals and the gyro frequency of electrons (ions), respectively; θ and α are the flow and aspect angles, respectively, defined previously; C_s is the ion-acoustic speed, $C_s \equiv \left[K_B\left(T_e + T_i\right)/m_i\right]^{1/2}$; and $\mathbf{V}_d$ is the differential plasma drift velocity, $\mathbf{V}_d \equiv \mathbf{V}_{e0} - \mathbf{V}_{i0}$ [6].

The electrons in the crossed electric, **E**, and magnetic, **B**, fields drift with the $\mathbf{E}\times\mathbf{B}$ drift velocity

$$\mathbf{V}_{e0} \cong \mathbf{V}_E = \mathbf{E}\times\mathbf{B}/B^2, \qquad (4)$$

while the ions drift with much slower speed approximately along the electric field (and hence perpendicular to $\mathbf{V}_E$)

$$\mathbf{V}_{i0} \cong \left[\Omega_i/\nu_i\right]\mathbf{E}/B, \qquad (5)$$

$$V_{i0} << V_{e0},$$

so that

$$V_{ph} = \frac{V_d\cos\theta}{1+\Psi} + V_{i0}\sin\theta \cong \frac{V_d\cos\theta}{1+\Psi}. \qquad (6)$$

It immediately follows from the above that the phase velocity should be proportional to the cosine function of flow angle (cosine law), and that the coefficient of proportionality is slightly less than background plasma drift, V_d (for typical E-region heights, $\Psi << 1$). Figure 3a shows the expected flow-angle dependence of velocity from the linear theory by the solid curve. The curve shown was normalized to V_d. However, this prediction is valid only for relatively small flow angles $\theta <\sim 60°$, as the condition for positive growth rate, $\gamma > 0$ (unstable growing waves), stipulates that $V_{ph} > C_s$. From Equation (2) (using $V_{i0} << V_{e0}$), there exists a critical flow angle, θ_0, given by $V_d\cos\theta_0 = C_s\left(1+\Psi\right)$, above which $\gamma < 0$, and hence no linearly unstable waves are generated outside the so called FBI flow-angle cone, $\theta > \theta_0$. The two regions in the flow angle (inside-cone, linearly unstable, and outside-cone, linearly stable) are shown in Figure 3a as shaded rectangles. Also, the above prediction is valid only for very small aspect angles $\alpha <\sim 2°$, as the anisotropy factor, Ψ, becomes very large at $\alpha >\sim 2°$. This easily makes $\gamma < 0$, so that again no linearly unstable waves exist at large aspect angles (i.e., the waves are magnetic-field aligned).

With increasing aspect angle and factor Ψ, the phase velocity decreases, Equation (6). This is illustrated in Figure 3b, which shows by the solid curve the expected phase velocity as a function of the aspect angle, α, at zero flow angle, $\theta = 0$. The phase velocity shown was calculated for typical collision frequencies, and was normalized to V_d.

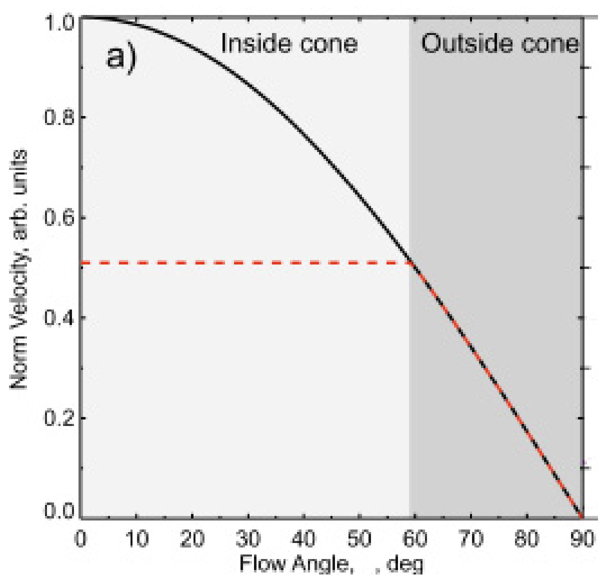

Figure 3a. The flow-angle dependence of the normalized phase velocity in the linear (solid curve) and C_s -saturated (dashed) regimes.

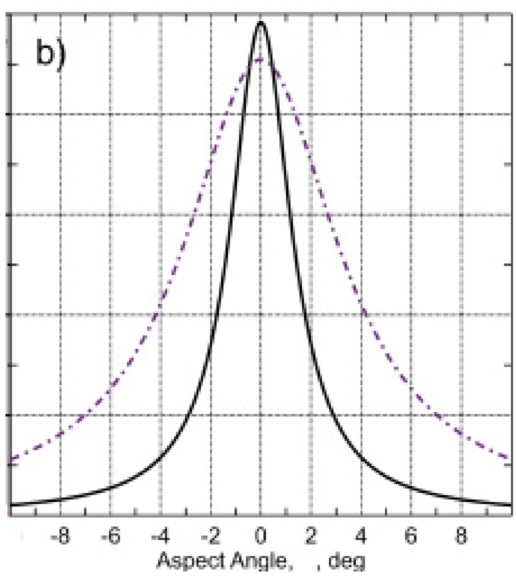

Figure 3b. The aspect-angle dependence as predicted by the linear theory (solid curve) and the theory of "anomalous collisions" (dash-dotted curve).

The linear theory implies a wave growing indefinitely with the rate given by Equation (2). One problem that needs to be resolved is thus how the wave reaches its saturation state, i.e., where the wave amplitude is stable, or, in other words, where the growth rate is zero, $\gamma = 0$. A common approach is to assume that one of the "given" background parameters (e.g., electric field) is modified by the wave in such a way that $\gamma = 0$. From Equation (2), $V_{ph} \cong C_s$ in this final saturated state. This is illustrated by the dashed curve in Figure 3a. A result of the saturation process is that the phase velocity should be smaller than the driving background convection-velocity component, $V_{e0} \cos\theta$, inside the cone (Figure 3a).

However, outside the cone, no linearly unstable waves should exist at all. The waves observed experimentally at large flow angles, outside the FBI cone $\theta > \theta_0$, are usually explained through a transfer of energy from linearly unstable modes within the FBI cone to linearly stable modes, outside the cone [14]. The phase velocity of the outside-cone modes is significantly more difficult to predict. It is often assumed to be equal to the velocity given by the linear theory, which was confirmed to some extent by numerical simulations [15], nonlinear considerations [16], and radar observations [2]. This is also illustrated in Figure 3a, in which the phase velocities in the linear and saturated regimes are shown to be the same outside the cone.

The theory of anomalous collisions [17] considered the effects of electron scattering by the FB waves. It established that one can treat these effects by essentially replacing ν_e in the expression for the anisotropy factor, Equation (3), by the enhanced (due to the particle-wave interaction) collision frequency, ν^* . This effective collision frequency increases until the factor Ψ^* is large enough for the phase velocity, V_{ph} , to become equal to the ion acoustic speed, C_s , which results in the saturation of the growth rate $\gamma = 0$ from Equation (2) (neglecting the ion-drift contribution). The theory of anomalous collisions contains one important prediction, i.e., that the anomalous collision frequency, ν^* , should be a decreasing function of the flow angle θ , as V_{ph} is smaller at nonzero flow angles, so that a smaller increase in ν^* (and Ψ^*) is required to reach $V_{ph} = C_s$. Ultimately, no increase in ν^* should be observed at $\theta = \theta_0$, since $V_{ph}(\theta_0) = C_s$ by the definition of θ_0 .

Although this theory was developed for zero aspect angle, prediction of the theory was applied later to the case of nonzero aspect angles, in response to new experimental data on the aspect-angle variation of the Doppler velocity. Under this assumption, because the electron collision frequency is enhanced due to the wave-particle interaction ($\nu_e \rightarrow \nu^* \cong 6\nu_e$), the aspect-angle dependence of the phase velocity becomes much weaker than predicted by the linear theory (the dash-dotted curve in Figure 3b).

However, one should bear in mind that several theoretical issues regarding the above substitution have been raised [8, 18, 19]. Therefore, the idea about the substitution of the nominal electron collision frequency by the anomalously large value in the expression for the phase velocity cannot be regarded as a theory. Rather, it represents the empirical knowledge derived from the observations of the E-region auroral echoes at large aspect angles.

3. Experimental Techniques and Data Analysis

3.1 Separation of the Flow and Aspect-Angle Effects

Theoretically, the flow and aspect angles are not related to one another. However, one of the greatest challenges in the velocity-data analysis is to distinguish between effects of the flow and aspect angles [19]. One approach is to select some specific azimuth of observations/radar beam and study how the phase velocity changes with the slant range along this radar direction [3, 4, 20]. In this approach it is assumed that the velocity variation is mostly due to aspect-angle change with the slant range, while the flow-angle effects are small (θ is fixed by fixing the azimuth), provided that the plasma flow across the radar field of view is fairly uniform.

However, the "opposite" separation of the flow-angle effects from those of the aspect angle is often difficult to achieve, first of all because the aspect angle is often dependent upon the direction of observation. For example, in Figure 2 the yellow line for KER is curved, so that the range at which the orthogonality condition is reached strongly depends on the radar beam/direction. One approach to the problem is to consider the echoes at smallest aspect angles for each radar beam, essentially fixing the aspect angle at minimum possible value [21]. Another potentially possible complication is that the rate at which the phase velocity decreases with α could be different for various flow angles, as was discussed in Section 2. This may potentially be the reason for some of the discrepancies in the observational results.

3.2 Estimates of the Electron Velocity and Flow Angle

In order to investigate the flow-angle dependence of the phase velocity, one needs to obtain estimates of the electron drift velocity, $\mathbf{V}_{e0}$. The same information is also required when studying the aspect-angle dependence, as one has to first remove the drift speed and flow-angle effects. Below, we discuss the methods that have been used, and indicate the recent studies that have employed these methods.

3.2.1 Incoherent-Scatter Radars (ISRs)

Figure 2 shows locations of the European Incoherent Scatter (EISCAT) tri-static facility and the Poker Flat incoherent-scatter radar (PFISR) by the yellow circles. Figure 2 also shows locations and viewing areas of both the Finland and Norway components of the bistatic VHF system STARE (Scandinavian Twin Auroral Radar Experiment), with the two radars located in Hankasalmi, Finland (HAN), and Midtsandan, Norway (MID). EISCAT was located within the STARE system field-of-view until May 2005, when STARE stopped its operations. PFISR is located within the field-of-view (FoV) of the imaging VHF radar in Anchorage, Alaska. EISCAT is the only incoherent-scatter radar system that is capable of directly measuring the three-dimensional plasma drift velocity, $\mathbf{V}_{e0}$. For this reason, it has been widely used in conjunction with STARE, including several recent studies [22-28]. The tri-static ion drift velocity measured by EISCAT in the F region is approximately the same as the electron drift velocity, $\mathbf{V}_{e0} = \mathbf{V}_{i0}$, as both ions and electrons move with $\mathbf{V}_E$ at these heights. Since the electron drift velocity, $\mathbf{V}_{e0}$, does not change much between the F- and E-region heights, it is projected along the magnetic field line to compare with the VHF velocity measured at the magnetic line footprint. This is illustrated in Figure 1, which shows the two field-perpendicular vectors, $\mathbf{V}_{e0}$, which were approximately the same. From the directions of $\mathbf{V}_{e0}$ and the radar-beam azimuth, the flow-angle estimates are also obtained. For a monostatic incoherent-scatter radar such as PFISR, the ion-drift component is often converted to the plasma drift speed by assuming an L-shell-aligned plasma flow, and dividing by the cosine of the L-shell angle (an angle between the radar-beam direction and the magnetic parallel or L shell) [29].

3.2.2 Sounding Rockets

In situ electric fields measured on sounding rockets in the E region are converted to the electron drift velocity assuming that the latter is $\mathbf{V}_E$, and taking a typical or model value for the magnetic field **B**. The electron drift velocity is then compared with the simultaneously measured Doppler velocity by coherent radars along the rocket trajectory [30, 29].

3.2.3 Low-Orbit Satellites

Although no satellites have orbits in the E region, because of the electrical link between the F and E regions ($\mathbf{V}_{e0}^F \cong \mathbf{V}_E \cong \mathbf{V}_{e0}^E$), the electric field is converted to the electron drift velocity, projected down the magnetic field line, and compared with coherent radar velocities measured at the footprint of the field line along the satellite's path. Because of the instrument limitations, often only the cross-track velocity component is considered, and only conjunctions with the radar beams closely aligned with the cross-track direction are selected [31].

3.2.4 HF Coherent Radars

Because of refraction, HF radars measure the irregularity velocity component in both the E and F regions (Figure 1). The F-region irregularities are believed to drift with $\mathbf{V}_{e0}$, and hence the line-of-sight component of $\mathbf{V}_{e0}$ can be compared with the E-region line-of-sight velocity measured at closer ranges along the same radar beam. The flow angles in this approach can be estimated either assuming an L-shell-aligned flow and taking the L-shell angle, ϕ, for the flow angle, θ, or inferring the F-region flow direction from observation using multiple beams [32, 21, 33]. Unlike the previous methods, where $\mathbf{V}_{e0}$ and V_{ph} were obtained either at the same location (Section 3.2.2) or on the same magnetic field line (Sections 3.2.1 and 3.2.3), in this approach estimates are obtained in locations separated by at least several hundred kilometers. Plasma-convection velocity can easily vary significantly along the radar beam, especially for more meridionally looking radars and beams. Therefore, events are sometimes selected when there are available data showing that convection velocity does not change significantly along the beam [21].

3.3 Estimates of the Ion-Acoustic Speed, C_s

3.3.1 Incoherent Scatter Radars

Incoherent-scatter radars measure the ion and electron temperatures at a range of heights encompassing the E region, from which the C_s can be estimated at different E-region heights.

3.3.2 Empirical Dependence on Plasma Drift Speed

The C_s was shown to depend on the electron drift speed due to electron heating by the FB waves, slowly increasing with V_{e0}. The empirical formula describing this dependence of the "disturbed" C_s at a height of 105 km has been derived as

$$C_s = A + BV_{e0}^2 , \quad (7)$$

where $A = V_{min}$ was found to be 300 and 400 m/s for eastward (evening sector) and westward (morning) electrojet observations, respectively, and $B = 1.1\times10^{-4}$ m^{-1}s [34]. The second value for A was used in our C_s calculations used in Figure 3a, with an enhanced C_s of ~ 500 m/s due to a relatively high electron drift speed of 1000 m/s. Reference [25] reported that the C_s values given by Equation (7) were considerably smaller than those estimated from the EISCAT measurements at 110 km. Slightly different values for the constants A and B were later adopted by [28], based on an extended EISCAT dataset in the afternoon sector (15-19 MLT), and a height of 110 km with $A = 380$ m/s and $B = 1.55\times10^{-4}$ $\mathrm{m}^{-1}\mathrm{s}$.

3.4 Estimates of Aspect Angle

The aspect angles for specific scattering locations are relatively easy to estimate for observations using VHF and UHF radars, as radio waves experience little refraction at these high frequencies. As a result, the radiowave propagation can be assumed to occur in straight lines and, hence, the geometrical or rectilinear aspect angles can be calculated for a particular scattering location using a magnetic-field model [35, 36, 27, 28]. A simple Geometrical Optics approach, involving refraction according to Snell's law, is often used when calculating aspect angles at HF [37, 38, 36, 20, 35, 21, 33]. In these calculations, a spherically-stratified ionosphere is assumed with a given electron-density height profile. More advanced methods used in both HF and VHF studies involve ray-tracing simulations and inclusion of altitude-integration effects [39, 23, 24, 26].

4. Flow-Angle Effects

A fundamental question that is also important for various applications is whether the phase-velocity variation with the flow angle obeys the cosine law (Section 2). A more general question is whether this variation can be explained by the linear theory.

It has long been thought that the answer appears to depend on the type of echoes observed. Narrow spectra, centered near the "undisturbed" C_s (350-450 m/s), termed Type I echoes, were observed mostly at small flow angles, inside the FBI flow-angle cone, $\theta < \theta_0$. They have been associated with the primary, linearly unstable FB waves. Wider spectra, with small Doppler shifts near zero, were observed at all flow angles, including outside the FBI flow-angle cone, $\theta > \theta_0$. These echoes were called Type II echoes, and attributed to the energy transfer from linearly unstable FB modes generated inside the cone.

4.1 Small Flow Angles, $\theta < \theta_0$

4.1.1 C_s Saturation

For waves propagating inside the FBI flow-angle cone, the Doppler velocity has been shown to be limited by the ion-acoustic speed, C_s [2, 34, 40], as observed by the STARE VHF radars at ~ 140 MHz. Evidence for C_s saturation was also presented at UHF [41, 42], and at HF [43]. This approach was later called the Ion Acoustic Approach, or IAA, and an example of "saturated" velocity at C_s is shown by the dashed curve in Figure 3a.

4.1.2 Velocity Variation with θ

Inconsistent with this simple idea of constant C_s are the observations showing velocity variation with θ [39, 22, 35]. Empirically, the STARE velocity at $\theta < 60°$ was found to vary as $C_s\left(\cos\theta/\cos\theta_{cr}\right)^{\beta}$, with β decreasing with the electron drift speed and $\theta_{cr} = 40°$ [22]. Figure 4 shows this empirical dependence for $\mathrm{V}_{e0} = 1000$ m/s by the dash-dotted line.

4.2 Large Flow Angles $\theta > \theta_0$

At large flow angles, $\theta >\sim 60°$, the E-region irregularity velocity has been shown to be largely consistent with the cosine law, $V_{e0}\cos\theta$, at various frequencies [2, 44, 42]. However, more-recent VHF and HF observations identified the cases when the cosine law has to be somewhat modified.

4.2.1 VHF Velocity Overspeed and Ion Drifts

During intervals of significantly enhanced electric fields, the STARE Finland radar velocity was larger than $V_{e0}\cos\theta$ [23, 24]. This "velocity overspeed" phenomenon was difficult to explain, as all theories imply that $V_{ph} \le V_{e0}\cos\theta$. It was argued that during uplifting of the E region, the bulk of the backscatter signal comes from the topside E region (near 120 km), where aspect angles are significantly larger. This corresponds to an increase in the factor Ψ, which is a fast-increasing function of α through Equation (3). A combination of two factors – an elevated anisotropy factor, Ψ, and a small electron-drift component at large flow angles, θ – makes it possible for the second term related to the ion motion in Equation (6) to become comparable with and even exceed the first electron-drift term at large flow angles. Such an approach was termed the off-orthogonal fluid approach (OOFA). A representative trend from [24] is shown in Figure 4 by the grey heavy curve $\beta V_{e0}\cos\left(\theta+\theta_1\right)$. The OOFA parameters adopted were $\theta_1 = 9°$ and $\beta = 0.55$. The velocity maximum was reached at $\theta_1 = 9°$. It was smaller than $V_{e0}\cos\theta$ at small flow angles, but exceeded it at large angles, $\theta >\sim 80°$ (velocity overspeed).

4.2.2 HF Velocity Magnitude

The E-region velocities measured with the SuperDARN radars were found to be too low to be consistent with the cosine law [20, 35, 21, 32]. The HF velocity variation with L-shell angle ϕ was proportional to $\cos\phi$,

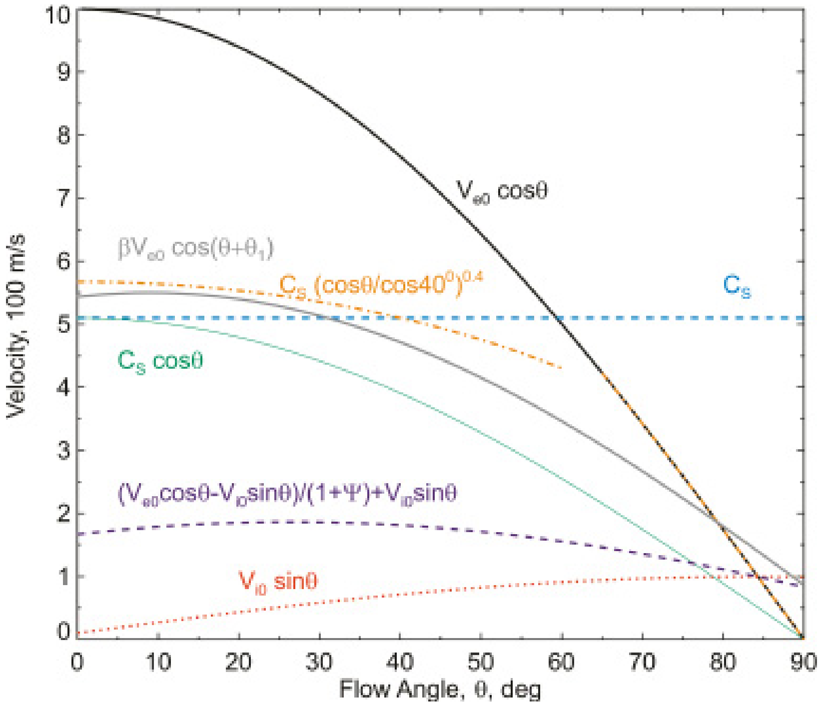

Figure 4. A summary of observations on flow-angle dependence (see text for details).

but with a relatively small coefficient of ~ 200 m/s [21]. Further comparisons with the simultaneously measured F-region velocities showed a factor of four to five [21, 31]. It was suggested that the HF velocities were reduced because of the large factor Ψ, due to higher collision frequencies at the bottom-side E region and/or nonzero aspect angles.

4.2.3 HF Velocity Direction

The two-dimensional HF velocity from HAN was shown to be rotated by up to 30° as compared to the F-region drifts [21]. Both directions were inferred from fitting the cosine-law curves to the simultaneously measured E- and F-region velocity data from all beams. This was interpreted as being due to the ion-drift contribution to V_{ph}, as described by the linear theory, Equation (6). Figure 4 shows the trend found to be representative of the HF velocities by the dashed curve. The ion drift velocity was calculated using Equation (5), with $\Omega_i / \nu_i = 10$ and $\Psi = 5$. The velocity maximum was reached at $\theta = 30°$, while the magnitude was ~ 200 m/s.

4.2.4 High-Aspect Irregularity Region (HAIR) Echoes at HF

The echoes in the first few range gates (< 360 km) from PYK and STO exhibited a velocity variation with *L*-shell angle ϕ that was consistent with $\sin\phi$, with a small coefficient ~100 m/s [45]. These echoes were interpreted as backscatter from large aspect angles where $\Psi >> 1$ and hence, from Equation (6), the phase velocity was equal to $V_{i0} \sin\theta$. Similarly to [21], it was assumed that $\Omega_i / \nu_i = 10$, and hence $V_{i0} = V_{e0}/10$. The model trend is shown by the dotted line in Figure 4.

4.2.5 VHF Velocity and Ion Drift Measurements in the E Region

Following the previously suggested idea that at large flow angles, the ion motions can dominate the electron motions, the STARE Finland velocity was compared with the ion drift velocities at several heights in the E region, as measured in a special EISCAT experiment [26]. The experiment largely confirmed this expectation, with the STARE velocity being predominantly between the ion drift components, $V_{i0} \sin\theta$, at 110 and 115 km, while agreement with the electron drift component, $V_{e0} \cos\theta$, was poor.

4.2.6 HF Velocity Independent of the Flow Angle

A separate population of HF echoes from SYE at ranges of 360-450 km exhibited an approximately constant velocity near 500 m/s, independent of the *L*-shell angle $\phi = 15°$ to $75°$ [33]. This included angles $\phi = 40°$ to $75°$ outside the FBI cone, as determined from the simultaneously measured F-region velocities. The HF velocities were near the presumptive C_s inferred from Equation (7). This constant C_s velocity is shown by the dashed horizontal line in Figure 4; it represents the reported velocities both inside and outside the FBI cone.

4.2.7 $C_s \cos\theta$ Model

A modification of the cosine law has been proposed by [30], based on the VHF imaging radar observations at 30 MHz performed in conjunction with the plasma-drift measurements by the JULIA I sounding rocket. The vast majority of VHF echoes had large spectral widths, and were therefore classified as Type II echoes, including those at relatively small flow angles, $\theta >\sim 5°$. The phase velocity of these echoes was found to be close to the presumptive C_s from Equation (7) multiplied by the cosine of the flow angle. Later, [29] confirmed this conclusion using observations collected during the JULIA II rocket experiment. However, in this case the measurements were offset from the formula $C_s \cos\theta$ by 100 m/s, which was close to the measured neutral wind velocity.

Several studies have also performed comparisons between different models of phase-velocity variation with θ. Reference [24] compared the IAA and OOFA performance at all flow angles, and found that OOFA performed better for moderate plasma flows. Reference [25] examined whether the VHF velocity at 140 MHz can indeed be described by the $C_s \cos\theta$ model using direct C_s estimates from EISCAT temperatures, rather than presumptive C_s from Equation (7). These authors found that OOFA appeared to perform better than the $C_s \cos\theta$ model or the empirical model of [22].

Later, [28] found that at small aspect angles, $\alpha < 1°$, the VHF velocity was described reasonably well either by the $V_{e0} \cos\theta$ formula or by the empirical formula of [22], $C_s \left(\cos\theta / \cos\theta_{cr}\right)^{\beta}$. The $C_s \cos\theta$ model significantly underestimated the VHF velocity. At large $\alpha > 1°$, the phase velocity increased with θ approximately as $V_{e0} \sin\theta / 4$. Similarly to [21] and [45], this was interpreted as being consistent with the $V_{i0} \sin\theta$ model, but in this case assuming that $\Omega_i / \nu_i = 4$ (previously, a factor of 10 was assumed), based on direct ion-drift measurements by [26].

5. Aspect-Angle Effects

Some consensus has emerged in the past, i.e., that the aspect-angle effects tend to be weaker as compared to those predicted by the linear theory, as was discussed in Section 2, and can be reasonably well described by the "anomalous collisions" idea. New observations described below suggest that this appears to be applicable only at small flow angles, $\theta < \theta_0$. At intermediate flow angles, near the FBI flow-angle cone, $\theta \cong \theta_0$, as well as at large flow angles, $\theta > \theta_0$, other effects become important.

Figure 5 shows the approximate coverage of various radar systems used in the past in the aspect and flow angles. Several filled rectangles were shifted slightly to avoid some of them being hidden. Most previous studies have concentrated on the small flow angle observations, with the results almost universally being consistent with the anomalous collisions idea [3, 46, 4, 47, 19, 5, 20]. This is indicated by the symbol "ν^*" placed in the left-bottom corner of the rectangles.

5.1 HF Velocity Variation with α at Large Flow Angles

Reference [20] employed the SuperDARN PGR radar and demonstrated that the HF velocity variation with range and expected aspect angle was consistent with the anomalous collisions idea in the beams with the smallest *L*-shell angles ($\phi = 40°$ to 50°). However, in the radar beams with the largest angles, $\phi = 70°$ to 90°, very little variation was observed. This is illustrated by the symbol "C" (for constant) in the corner of the second rectangle corresponding to that study in Figure 5. It was proposed that at large flow angles, near 90°, the first term in Equation (6) is small, so that most of the contribution to the phase velocity comes from the second, ion-drift term. This term does not depend upon the factor Ψ, and hence upon the aspect angle.

5.2 HF Velocity Increase with α

Using SuperDARN HAN observations at large *L*-shell angles ϕ, [21] demonstrated that the HF velocity magnitude decreased with expected aspect angle at $\phi = 40°$ to 80°, while at larger $\phi = 80°$ to 110°, an unexpected increase was observed. Although the rate of decrease was not under consideration, qualitatively this behavior was explained by the linear fluid theory involving an ion-drift contribution to the phase velocity. This is shown by the symbol "L" (for linear) in the rectangle corresponding to that study in Figure 5.

5.3 VHF Velocity Decrease with α at Intermediate Flow Angles

In an attempt to properly separate the direct effects of the flow and aspect angles, a scanning-beam experiment was performed [27, 28]. In this experiment, EISCAT obtained tri-static plasma-drift measurements on the same field lines as seven locations with different geometric aspect angles monitored by the STARE Norway VHF radar. The comparisons showed that at intermediate flow angles, near the FBI instability cone $\theta = 50°$ to 70°, the phase-velocity decrease with aspect angle was consistent with that predicted by the linear theory (this decrease is shown in Figure 3b by the solid line). This was interpreted as possibly being due to smaller enhancements in anomalous collision frequency, ν^*, required to saturate the growth rate near the FBI cone boundary, as predicted by the theory of [17] (see our Section 2).

5.4 VHF Velocity Variation with α at Large Flow Angles

From the same experiment, [28] demonstrated that the VHF velocity exhibited little variation with aspect angle at $\theta = 70°$ to 90°, a result similar to that of [20] at HF. A similar explanation, based on the ion-drift contribution to the phase velocity as described by Equation (6), was proposed. It was also argued that in order to estimate the amount of anomalous collisions ν^* or Ψ^*, it may be insufficient to have the electron drift measurements alone and normalize to V_{e0}, as was done in the past. Since Equation (6) contains both terms, one needs to employ the ion-drift measurements, as well.

The recent observations of the aspect-angle dependence described above thus appear to differ significantly from those performed in the past. The velocity decrease with the aspect angle α at intermediate flow angles, $\theta \cong \theta_0$, was stronger than reported before so that it was described well by the linear theory trend. On the other hand, at large flow angles, $\theta > \theta_0$, either almost no velocity variation or even a small velocity increase was observed. The summary of observations presented in Figure 5 suggests that while at small flow angles the anomalous-collisions idea well represents the observations, at large flow angles, $\theta > 50°$, it fails to do so, in agreement with expectations of the theory of [17]. On the other hand, the attempts to interpret these observations in terms of the linear fluid theory have been largely successful.

6. New Applications in Linear Fluid Theory

New evidence derived from coherent radar measurements of the E-region irregularity velocity suggest that the Doppler-velocity variation with the flow and aspect angles can often be described reasonably well by the linear fluid theory, Equation (6). New developments in the application of the theory include consideration of the effects of the ion drifts and the non-orthogonality of backscatter.

6.1 Off-Orthogonal Backscatter

The anisotropy factor, Ψ, is a fast-increasing function of the aspect angle, α (see Equation (3)). This results in a strong reduction in the phase velocity (Equation (1)). This idea has been recently used in an attempt to explain unusually low values for the Doppler velocities observed at HF (Section 4.2.2). Despite this idea being rather obvious, it was not quite clear why the aspect angles were not zero (or very small), as, according to the same theory, the backscatter should be predominantly coming from locations with $\alpha \cong 0$.

A possible explanation is offered if one considers the altitude-integration effects [48, 23, 24, 26]. When observing a certain radar cell, the radar integrates over a range of E-region heights. Due to the height variation of the scattering cross section, the bulk of the backscattered power comes from a certain altitude, which is determined by altitude

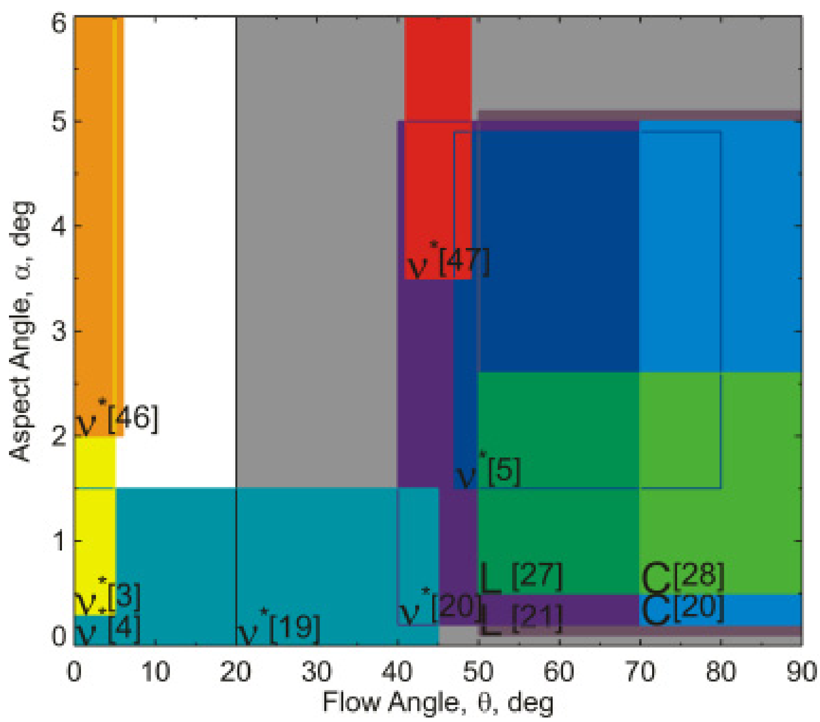

Figure 5. A summary of observations on aspect-angle dependence. Shown is the approximate coverage in flow and aspect angles for various experimental studies. A symbol in the bottom-left corner of the coverage area indicates whether the experimental data were consistent with the theory of anomalous collisions, "ν^*"; linear theory, "L"; or approximately constant variation, "C".

profiles of the density and aspect angle. In this model, the minimum aspect angle can easily reach 0.8° to 1.0°, even at VHF [23], which supports conclusions based on the HF observations.

6.2 Ion Motions

It has been suggested by a number of earlier studies that the ion-drift velocity contribution to the E-region irregularity velocity should be considered [49, 50, 39]. Recent studies have taken this idea further by concluding that this contribution can be either comparable with that of the electrons at large flow angles [23, 24, 21], or even completely dominate the phase velocity [20, 45, 51, 26, 28].

Indeed, from Equation (1), the relative importance of the electron and ion-drift contributions depends on the factor Ψ, with the ion-drift contribution increasing with Ψ. The anisotropy factor has been suggested to increase due to a higher collision frequency at the E-region bottomside and/or non-zero aspect angles. An additional factor is a decrease (increase) in the factor $\cos\theta$ ($\sin\theta$) in Equation (6) with flow angle θ, so that at large flow angles one expects the ion-drift effects to be more pronounced. The four trends in Figure 4 (black solid, $V_{e0}\cos\theta$; grey solid, $\beta V_{e0}\cos(\theta+\theta_1)$; dashed, $(V_{e0}\cos\theta - V_{i0}\sin\theta)/(1+\Psi)+V_{i0}\sin\theta$; and dotted, $V_{i0}\sin\theta$) can all be described by the linear theory with different values for Ψ. The two extreme cases of $\Psi << 1$ and $\Psi >> 1$ correspond to the first and last curves, respectively.

Similarly, Figure 5 shows that most observations at large flow angles were consistent with the linear theory, either in terms of rate of decrease ("L") or as showing little variation with α ("C"). The latter effect and an unusual velocity increase with α reported by [21] have been explained by the ion-drift contribution.

6.3 Inconsistent Observations

The observations inconsistent with the linear fluid theory (in its broader meaning encompassing the four above-mentioned trends) were predominantly obtained at small flow angles. Thus, Figure 5 shows that in all observations at $\theta < 50°$, the velocity decrease with α was consistent with the anomalous-collisions idea ("ν^*").

In terms of the flow-angle dependence, the interpretation/model commonly involved the ion-acoustic speed, C_s. In the empirical model of [22], the phase velocity exceeded C_s by a factor of ~ 1.1 at $\theta = 0$, while in the $C_s\cos\theta$ model of [30], $V_{ph} = C_s$ at $\theta = 0$ (Figure 4). However, one can notice that at $\theta <\sim 20°$, both models (dash-dotted and thin solid curves) were relatively close to the dashed line of constant C_s, as well as to the OOFA model trend (grey solid line). This suggests that in this range of flow angles, it may be difficult to differentiate between various models. Where the models deviate significantly from C_s, the flow angles were 30° to 60°. It is in this range where more observations are needed.

To the best of our knowledge, the only result inconsistent with the linear theory at large flow angles was obtained by [33] (Section 4.2.6), as is illustrated by the dashed horizontal curve in Figure 4. This trend was observed only for one population of echoes, in ranges 360 to 450 km, located farther from the radar than the other (low-velocity) echo population that exhibited a cosine-like velocity variation. It has been suggested that these echoes might have come from the topside E region, where the plasma-instability processes may have been different from the FBI. It is therefore highly desirable to have the altitude information (which was not available in that study), in order to distinguish between echoes generated by different mechanisms and to possibly reconcile different models.

7. Future Directions

As was discussed in Section 3, knowledge of the electron drift velocity, $\mathbf{V}_{e0}$, and the ion-acoustic speed, C_s, are crucial in studying the flow-angle dependence of the E-region irregularity velocity. Such opportunities are rare. The ion-drift measurements from EISCAT used extensively in the past were performed in a very small region of the high-latitude ionosphere. They normally referred to slant ranges that corresponded to F-region observations in the SuperDARN HF data (Figure 2), while the STARE VHF system is no longer operational. It is possible to use EISCAT in a different mode, with the beam inclined equatorward towards HAN, but, unfortunately, technical restrictions on the EISCAT beam elevation do not allow the E-region footprint to be reached.

New exciting opportunities are provided with the recent deployment of the PFISR system. Although PFISR is not a tri-static radar, much faster scan times allow the beam-swinging technique to be employed. Being located in the field of view of the VHF radar in Anchorage (see Figure 2), and close to the E-region footprint of the KOD HF radar, PFISR is an excellent tool for E-region irregularity studies.

The paired SuperDARN HF radars are specifically designed to produce two-dimensional vectors $\mathbf{V}_{e0}$. Even a single radar is capable of providing useful information about the electron-drift component in conjunction with the E-region velocity measurements, as a number of recent studies have successfully demonstrated. A number of new SuperDARN radars that have been recently deployed provide an opportunity to study E-region velocities in the context of F-region drift measurements on the same field line. Examples of this configuration are the RNK radar, which is also covered by the KAP-SAS combination, and the similar INV-KOD-PGR conjunction (Figure 2). Additional (to

WAL and BLK) proposed radars in mid-latitudes in the US would create similar configurations involving auroral E-region observations by the PGR and KAP radars.

8. Conclusions

In this report, we presented an up-to-date review of our knowledge of the E-region auroral irregularities derived from coherent radar measurements of the Doppler velocity. New experimental observations of the E-region irregularity velocity dependence upon the flow and aspect angles suggest the following:

1. At small flow angles, the velocity is considerably smaller than the cosine component of the electron drift velocity. The velocity decrease with the flow angle can nevertheless be described by the cosine-law formula, with the coefficient (velocity along the electron flow) suggested to be either the reduced electron drift velocity or the ion-acoustic speed. The velocity decrease with the aspect angle is weaker than that predicted by the linear theory.

2. At intermediate flow angles near the FBI flow-angle cone, the irregularity velocity is close to the electron drift component, and decreases with the aspect angle at a rate close to that given by the linear theory.

3. At large flow angles, the velocity often exceeds the electron drift component and exhibits little variation with the aspect angle. Its variations with both the flow and aspect angles can be described by the linear theory, if the contribution from the ion-drift motions is taken into account.

4. The E-region echoes from different populations often exhibit significantly different variations with the flow angle, which suggests that more studies are needed with proper separation of echoes of different origin.

Overall, the linear fluid theory of the E-region irregularities provides a very useful framework for interpreting coherent Doppler radar measurements. This is particularly true for observations at intermediate and large flow angles, and when simultaneous ion-drift measurements are available.

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IUCAF Annual Report for 2008

1. Introduction

The Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science, IUCAF, was formed in 1960 by its sponsoring Scientific Unions, COSPAR, the IAU, and URSI. Its brief is to study and coordinate the requirements of radio frequency allocations for passive (i.e., non-emitting) radio sciences, such as radio astronomy, space research and remote sensing, in order to make these requirements known to the national and international bodies that allocate frequencies. IUCAF operates as a standing interdisciplinary committee under the auspices of ICSU, the International Council for Science. IUCAF is a Sector Member of the International Telecommunication Union (ITU).

2. Membership

At the end of 2008 the composition of membership for IUCAF was:

URSI	S. Ananthakrishnan (Com J)	India
	S. Reising (Com F)	USA
	I. Häggström (Com G)	Sweden
	A. Tzioumis (Com J; vice-chair)	Australia
	W. van Driel (Com J; Chair)	France
IAU	H. Chung	Korea
	D.T. Emerson	USA
	M. Ohishi	Japan
	K.F. Tapping	Canada
	A. Tiplady	S. Africa
COSPAR	Y. Murata	Japan
at large:	W.A. Baan	Netherlands
	K. Ruf	Germany

IUCAF also has a group of Correspondents, in order to improve its global geographic representation and for issues on spectrum regulation concerning astronomical observations in the optical and infrared domains.

3. International Meetings

During the period of January to December 2008, its Members and Correspondents represented IUCAF in the following international meetings:

April	ITU-R Working Party 7D (radio astronomy) in Geneva, Switzerland
July	37th COSPAR Scientific Assembly, in Montreal, Canada
August	XXIX URSI General Assembly, in Chicago, USA
September	Space Frequency Coordination Group meeting SFCG-28 in Quebec City, Canada
October	ITU-R Working Party 7D (radio astronomy) in Geneva, Switzerland

Additionally, many IUCAF members and Correspondents participated in numerous national or regional meetings (including CORF, CRAF, RAFCAP, the FCC etc.), dealing with spectrum management issues, such as the preparation of input documents to various ITU fora.

3.1 IUCAF Business Meetings

During 2008 IUCAF had a face-to-face committee meeting before each of the ITU meetings listed above, with the purpose of discussing issues on the agenda of the meetings in preparation for the public sessions. During these ITU sessions ad-hoc meetings of IUCAF were held to discuss further its strategy. Also discussed was other IUCAF business, such as action plans for future workshops and summer schools or initiatives and future contributions to international spectrum management meetings. Although such face-to-face meetings have been convenient and effective, throughout the year much IUCAF business is undertaken via e-mail communications between the members and correspondents.

4. Contact with the Sponsoring Unions and ICSU

IUCAF maintains regular contact with its supporting Scientific Unions and with ICSU. The Unions play a strong supporting role for IUCAF and the membership is greatly encouraged by their support.

Pursuing its brief, IUCAF continued its activities towards strengthening its links with other passive radio science communities, in particular in space science, and defining a concerted strategy in common spectrum management issues.

At the 37th COSPAR Scientific Assembly, IUCAF organized Scientific Event E110 on "Spectrum Management and COSPAR: Keeping Passive Radio Observations Free of Interference", where 7 presentations were given by representatives of the ground-based and space-borne radio astronomy and remote sensing community. The session was attended by about 25 participants.

The IUCAF Chair is a member of the Organizing Committee of IAU Commission 50 on the Protection of Existing and Potential Observatory Sites, IUCAF vice-chair A. Tzioumis is Chair of the Working Group on Radio Frequency Interference of IAU Division X (radio astronomy), and IUCAF member M. Ohishi chairs the Working Group on Astrophysically Important Spectral Lines of Division X.

At the XXIX URSI Scientific Assembly, IUCAF organized its open meeting during session J07, and IUCAF members were also actively involved in the organization of the Joint Session on Solar Power Satellites. In 2008, IUCAF members also actively participated in national URSI meetings.

5. Protecting the Pasive Radio Science Services

At the ITU, the work in the various Working Parties of interest to IUCAF was focused on the relevant agenda items that were adopted in 2007 for WRC-11, the 2011 ITU World Radiocommunication Conference, as well as on revision and maintenance of various ITU-R Recommendations and the drafting of new ITU-R Reports.

The WRC-11 agenda item most relevant to radio astronomy concerns the use of the radio spectrum between 275 and 3000 GHz. No allocations for the use of this frequency band will be made at WRC-11, but the radio astronomy community has to identify a list of specific bands of interest. This list is being established in close collaboration with the IAU.

Work was started towards a revision of ITU-R RA.1513 on "Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference […]", in order to define a better way to assess RFI that is highly variable in time or/and frequency.

Work was started towards a new ITU-R Report on "The essential role and global importance of radio spectrum use for Earth observations […] and for other related science applications", which contains a description of benefits from spectrum use by radio astronomy and space research.

Work was started towards a new ITU-R Report on "Characteristics of Radio Quiet Zones" for radio astronomy. IUCAF member M. Ohishi is Chair of ITU-R Working Party 7D (radio astronomy) and IUCAF member H. Chung is Vice-chair of ITU-R Study Group 7 (Science Services).

6. IUCAF-Sponsored Meetings

In 2008, IUCAF worked towards the organization of its third Summer School on Spectrum Management for Passive Radio Sciences, which was planned to be held in Korea in 2009.

7. Publications and Reports

IUCAF has a permanent web address, http://www.iucaf.org, where the latest updates on the organization's activities are made available. All contributions to IUCAF-sponsored meetings are made available on this website.

8. Conclusion

IUCAF interests and activities range from preserving what has been achieved through regulatory measures or mitigation techniques, to looking far into the future of high frequency use and giant radio telescope use. Current priorities, which will certainly keep us busy through the next years, include the use of satellite down-links close in frequency to the radio astronomy bands, the coordination of the operation in shared bands of radio observatories and powerful transmissions from downward-looking satellite radars, the possible detrimental effects of ultra-wide band (UWB) transmissions and high-frequency power line communications (HF-PLC) on all passive services, the scientific use of the 275 to 3000 GHz frequency range, and studies on the operational conditions that will allow the successful operation of future giant radio telescopes.

IUCAF is grateful for the moral and financial support that has been given for these continuing efforts by ICSU, COSPAR, the IAU, and URSI during the recent years. IUCAF also recognizes the support given by radio astronomy observatories, universities and national funding agencies to individual members in order to participate in the work of IUCAF.

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Radio-Frequency Radiation Safety and Health

James C. Lin

International Studies of Brain Tumors in Mobile-Phone Users' Heads

By now most readers have probably become very familiar with the refrain that "there is no overall risk of brain tumors with cellular mobile telephone use; however, for long-term mobile phone users, results need to be confirmed before definite conclusions can be drawn." Therein lies the dilemma: is there or isn't there a risk of brain tumors?

For nearly the entire year of 2008, the question hung on like a bad dream over many heads and just wouldn't go way. The non-believers have argued the "weight of evidence" is against any effect from wireless radiation from mobile phones to the point of taunting any scientific paper reporting a positive finding as "junk science." Needless to say, there are more than a few peer-reviewed scientific papers from major laboratories around the world reporting biological effects of mobile-phone radiation.

Regardless, the scientific community devoted to bioelectromagnetics research (and some others as well) have awaited with a great deal of anticipation the impending final report of the INTERPHONE project. This was launched by the International Agency for Research on Cancer (IARC), a health-related agency of the World Health Organization (WHO). This large, multinational program (13 countries in total; the US is not participating) was initiated to conduct a coordinated series of epidemiological studies to investigate the relationship between the incidence of cancers in the head and neck and the use of mobile phones [1]. The heightened interest was prompted, in part, by the projected date of program completion and the publication of several papers from INTERPHONE-related studies in the scientific literature [2]. Some of the results from the reported studies – especially those associated with use of a mobile phone for less than 10 years – were very similar to studies on short-term mobile-phone use. They showed no overall association between regular mobile-phone use and increased risk of malignant brain tumors with duration of use, years since first use, cumulative number of calls, or cumulative hours of use. However, the reported findings associated with the use of a mobile phone for 10 years or more have been intriguing, to say the least.

Specifically, a population-based, case-control study on the association of mobile-phone use with brain tumors in five northern European countries – Denmark, Finland, Norway, Sweden, and southeast England – where mobile phones have been widely used for at least a decade [3] reported a connection between malignant brain tumors and long-term use of a mobile phone. For 10 or more years of mobile-phone use, on the same side of the head where the tumor was located, an increased odds ratio (OR) of 1.39 was reported. (An OD of 1.0 is normal.) This indicates a 39% increase in the risk of gliomas in the ipsilateral side of the brain associated with long-term use of mobile phones.

The team from Germany also reported an increase in glioma following more than 10 years of mobile-phone use in a case-control study [4]. Specifically, among subjects who had used mobile phones for 10 years or more, an increased risk was reported for glioma (OR = 2.20). Since case-control studies relied on participants' reports of past phone use for their exposure assessment, errors in recalled phone use became a major concern, as effects of recall bias could not be ruled out. A recall bias tends to raise the risks. On the other hand, a selection bias would lower observed risks.

The French part of the INTERPHONE study focused on tumors of the brain and central nervous system: gliomas, meningiomas, and acoustic neuromas [5]. Results indicated that in general, regular mobile phone use was not associated with an increased risk of acoustic neuroma (OR = 0.92),

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meningioma (OR = 0.74), or glioma (OR = 1.15). However, although not statistically significant, the report showed a general tendency toward an increased risk of glioma among the heaviest users: long-term users, heavy users, users with the largest numbers of mobile phones.

Because the number of long-term mobile-phone users in these studies was small, the statistical power was limited. Thus, the possibility of an elevated risk of glioma in long-term mobile-phone users or after 10 years or more of mobile-phone use ought to be further confirmed: perhaps by subsequent reports from other participating countries and research groups or, more fittingly, by the final report of the INTERPHONE project. However, to date, the final INTERPHONE report has yet to be published.

In the meantime, the INTERPHONE study from Israel [6] to assess the association between mobile-phone use and the development of parotid gland tumors reported an elevated risk in regular users or under conditions that may yield higher levels of exposure (e.g., heavy use in rural areas). For ipsilateral use, the odds ratios in the highest categories of cumulative number of calls and call time without use of hands-free devices were 1.58 and 1.49, respectively. A positive dose-response trend was found for these measurements. The authors concluded that based on the largest number of benign parotid gland patients reported to date, their results suggest an association between mobile-phone use and parotid gland tumors.

The nonappearance of the INTERPHONE analysis and publication of IARC's final report has prompted numerous speculations about why the delay, and when will it appear. "Soon, I hope," was the reply from Elisabeth Cardis, the head of the INTERPHONE project, when she was asked at last June's Bioelectromagnetics Society (BEMS) annual scientific meeting in San Diego. What has become obvious is that there is persistent concern about the possible adverse health effects of cellular mobile-telephone radiation.

Shortly after the BEMS meeting, a group of 20 cancer and public health specialists in France publicized an appeal for caution in the use of mobile phones in the June 15, 2008, issue of the *Journal du Dimanche* newspaper. The group was later joined by three Americans. Among them was Ronald Herberman, the director of the University of Pittsburgh Cancer Institute. On July 23, 2008, Dr. Herberman sent a memo to the Institute's faculty and staff, saying, "I have become aware of the growing body of literature linking long-term mobile phone use to possible adverse health effects including cancer. Although the evidence is still controversial, I am convinced that there are sufficient data to warrant issuing an advisory to share some precautionary advice on mobile phone use." The memo was featured on the front page of the Pittsburgh Post-Gazette on the same day. Both the appeal and the memo received widespread coverage in the worldwide media – so much so that they prompted Dennis Kucinich, a US Congressman from Ohio and Chair of the Domestic Policy Oversight Subcommittee, to conduct the first Congressional hearing on mobile phones in 15 years.

One would be well advised not to read too much into the recent congressional hearing. One of the distinguishing features of the mobile-phone radiation health-effect research has been the lack of interest from the US research funding or public-health-related agencies. However, it has been estimated that there are more than two billion users of cellular mobile telephones worldwide, and well over 200 million in the US. The popularity of mobile phones is beyond any debate. It's a good guess that most, if not all users, manufacturers, and wireless operators, would prefer no links between cellular mobile telephone and health effects, let alone mobile-phone use and cancer.

The September 23, 2008, issue of the NCI Cancer Bulletin included the following quote: "We now have studies covering up to 10 years of mobile phone usage, and we're still not seeing any convincing evidence of an increased brain cancer risk," by Peter Inskip of the US National Cancer Institute's Division of Cancer Epidemiology and Genetics. The article concluded with a note from Dr. Inskip, "Of all the potential health risks associated with mobile phones that have been examined so far, the most convincing evidence concerns the risk of motor vehicle accidents among people distracted by using their mobile phone while driving."

Apparently, the views expressed in the NCI Cancer Bulletin were primarily based on studies covering up to 10 years of mobile-phone usage. It is noteworthy that brain tumors are known to have latencies longer than 10 years. Regardless, the risk of brain tumors from mobile-phone exposures will likely remain controversial for sometime – even with (and without) the eventual publication of INTERPHONE's final (summary) paper, given its well-publicized and difficult birthing process.

As I wrote this article in December 2008, a new publication from the same above-mentioned five northern European countries [7] concluded that their "study does not provide evidence for an increased risk of meningioma in relation to mobile phone use." This was a collaborative case-control study involving 1209 meningioma cases and 3299 population-based controls. The paper reported lowered risks of meningioma (OR = 0.76) among regular users of mobile phones (at least once a week for at least six months). The risk was not increased with regard to years since first use (up to 10 years of mobile-phone usage), lifetime years of use, cumulative hours of use, or cumulative number of mobile-phone calls. The finding was comparable to the observation made by the French INTERPHONE group on the risk for meningioma (OR = 0.74), where they showed a general tendency toward an increased risk of glioma among the heaviest users: long-term users, heavy users, users with the largest numbers of mobile phones. It is interesting to note that in the latest report, the calculated ORs were all lower than 1.0, with the sole exception of an increased risk (OR = 1.87) related to 10 years or longer since first use of a digital mobile phone.

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Triennial Commission Report

COMMISSION D

This report was prepared by Dr. F. De Fornel, Commission D Chair 2006-2008.

1) Support of Meetings

During this triennial covering the period of October 2005 to August 2008 has supported the following conferences:

- APMC 2006 Asia-Pacific Microwave conference , Yokohama, Japan, 12-15 -december 2006
- Telecom & JFMMA, Fes, Morocco, 14-16 March 2007
- EMC Zurich 2007, Muenchen, Germany, 24-28 September 2007
- Metamarerial's 2007 The first International Congres on Advanced Electromagnetic Materials for Microwaves and Optics, Rome, Italia, 22-2- October 2007
- ISSSE 2007, Montreal, Canada , 30July- 2 August 2007
- EMC 2009 VIII International Symposium and Exhibition on Electromagnetic Compatibility and Electromagnetic Ecology, St Petersburg, Russia, June 2009

2) Commission D – Scientific

D commission have supported new domain of Nanosciences and thus, a few issues have emerged.

2.1 New scientific research areas

New research areas, like nanooptics and nanoelectronics have emerged as a result of innovative thinking. The URSI communauty is still to dispersed. D commission needs effort to have a common action with other scientifics organism.

2.2 New applied research areas

The emergence of NanoTechnology in the domain of RFID has changed the sensor technology. Inceasing collaboration with other Commissions, , becoms a necessity.

2.3 Microwave and millimeter wave imaging

Microwave and millimeter wave imaging is a domain in full development. The interest of such a domain concerns directly the D commission.

3) Commission D Scientific Program at the URSI GA 2008

3.1 Oral Sessions

RFID Technology and Applications,
Convener : Prof. S. Tedjini, INPGrenoble

Summary: The birth of the Radio Frequency IDentification (RFID) was in October 1948 after the paper of H. Stockman "Communications by Means of Reflected Power". One of the first application was "Identification of Friend of Foe" (IFF) for aircraft. Nowadays, the technological advances in microelectronics, microwaves, and embedded software are drastically expanding the application field of the RFID. This session will address the current development of RFID system including tags and readers.

Optical Devices includind guided waves
Proposer : Prof. Thyagarajan K. Thyagarajan

Summary: This session could include both linear and nonlinear optical effects in guided waves. It concerns plasmonic optical waveguides, waveguides based on photonic crystals and Bragg effects, parametric down conversion and four waves mixing in guided waves to generate entangled photon pairs etc.

Surface Plasmon (DB)
Conveners : F. de Fornel (com. D)
Nader Engheta (com B)
H. Nedwill Ramsey (com B)

Summary: Surface plasmons are interfacial electromagnetic modes that can be exploited to control the propagation and local oscillation of electromagnetic energy. This topical conference will explore fundamental and applied plasmonic concepts, the control and manipulation of local and propagating surface plasmons, plasmon dynamics, and novel plasmonic nanostructures.

Transistor session
Convener : Mikael Östling

Summary:
The session called "Ultimate limits in transistor performances" should be composed of a series of different

invited talks where each talk should focus on a particular transistor technology. The session should cover;

1) Ultimate high frequency performance bipolar transistors in SiGe HBT technology as well as in III-V technology

2) Ultimate high frequency CMOS transistor performances

3) Ultimate high frequency performances for emerging techniques. i.e carbon nanotube transistors

4) Ultimate high speed performances in spintronic tranistor technology.

Modeling of high frequency devices and circuits."
Convener : Samir M. El-Ghazaly Samir

Summary: The demand for high-frequency devices and circuits is steadily growing. Increased commercial and personal use of wireless technology is a major driver for the increased demand. Moreover, there is a staggering need for high-speed digital circuits to satisfy the requirements for faster computers, which proliferate in the form of computational tools or as embedded systems. The main characteristics of new technologies include high-density circuits, relentless miniaturization, low-cost materials, low power, and fast design cycles. To meet strict standards and satisfy often-conflicting requirements, device and circuit designers rely heavily on accurate modelling tools to achieve first-path success. Hence, new device and circuit modelling and simulation tools are needed. This session reviews the latest developments in this area.

3.2 Tutorial D

Manipulating light on a silicon chip
Speaker : Mickal Lipson, Cornell University

3.3 Poster Sessions I and II

Conveners: F. de Fornel, F. Kaertner

Summary: Contributed papers related to :

(a) Electronic devices, circuits, systems and applications;
(b) Photonic devices, systems and applications;
(c) Physics, materials, CAD, technology and reliability of electronic and photonic devices *down to nanoscale including quantum devices*, with particular reference to radio science and telecommunications.

XXIXth General Assembly

BUSINESS TRANSACTED BY COMMISSION F

Chair: Prof. P. Sobieski
Vice-Chair: Prof. M. Chandra

Comission F held three Business Meetings on Monday, August 11th, Wednesday, August 13th and Friday, August 15th.

Topic 1: Agenda (A)

Action: The agenda was tacitly agreed. No additional points were raised

Topic 2: Verification of credentials

Action: The credentials of the voting members were verified.

Topic 3: Election of Vice Chair for 2008-2011

Action: Prof. R. Lang (USA) was elected as the new incoming vice-chair. At the following council meeting this result of the election was confirmed.

Topic 4: Scrutiny of the 2008 GA programme

Action: The rule that paper contributions of up to four pages were required was not clearly understood by the authors. The commission members suggested a better and clearer wording of author instructions for the next GA. All members however agreed that the maximum length of four pages per paper was appropriate and acceptable.

Topic 5: Consider the request from Coordinating Committee and Council

to propose ideas towards white papers and the inclusion of scientific activities in the area of navigation and global positioning systems (GPS/GNSS).

Action:

1. The incoming chair (Prof. M. Chandra) detailed to the members the suggestion, initiated by the URSI president Francois Lefeuvre and other French members (Jean Isnard and Joel Hamelin), namely, that Commission-F took lead in creating a white paper on the subject of remote sensing and disaster management. All members agreed to support the idea. It was suggested that Prof. M. Chandra, in consultation with Jean Isnard and Francois Lefeuvre, should embark on this project. It was also suggested that during the first half of 2009 the three named persons should meet and identify a work plan in achieving this goal. The three named persons agreed to meet regularly (opportunity permitting) either in France or in Germany or on the sidelines of URSI conferences. M. Chandra suggested that for logistic ease, the region of Strasbourg lends itself as a suitable venue for meetings directed towards this action.
2. The members of the commission agreed to promote the inclusion of GPS/GNSS topics in the scientific activities at national level and at international level (particularly Commission-F conferences and Commission-F sponsored conferences).

Topic 6: Discussion about the Radio Science Bulletin

Action: The new incoming vice-chair, Roger Lang, in keeping with URSI tradition, was named the next editor and facilitator for Commission-F contributions to the Radio Science Bulletin. The presenters of the Commission-F review talks were reminded that they are expected to make submissions to the RSB. M. Chandra and Roger Lang agreed to follow this action.

Topic 7: Request for proposals of web-course in Commission-F competence directed toward developing countries

Action: The members agreed to come up with suggestions for improving the visibility of Commission-F activities on the official website. The members suggested that paper contributions of major Commission-F conferences should be posted on the commission's official website. The possibility of offering web courses on Commission-F topics was also briefly discussed. There were no immediate offers. M. Chandra suggested that short web courses could be offered as a prelude to major URSI-F conferences.

Topic 8: Discussion of terms of reference (B)

Commission F comprises two closely related fields, wave propagation and remote sensing and, based on the Terms of Reference updated at the 2005 General Assembly, encourages research in these fields at all frequencies, in particular, the Commission encourages :

(a) The study of all frequencies in a non-ionised environment
   (i) wave propagation through planetary, neutral atmospheres and surfaces;
   (ii) wave interaction with the planetary atmospheres, surfaces (including land, ocean and ice), and subsurfaces;
   (iii) characterisation of the environment as it affects

wave phenomena;

(b) The application of the results of these studies, particularly in the areas of remote sensing and communications;

(c) The appropriate co-operation with other URSI Commissions and other relevant organisations.

Action: No change was deemed necessary.

Topic 9: Anticipated inter-assembly meetings

Action

Type A meetings

- MicroRAD2009
- COSPAR
- IGARSS2009
- IGARSS2010
- AP-RASC2009
- AP-RASC2009
- ISMOT-2009
- ISAP'2009
- MicroRAD2010
- EUSAR 2010

Type B meetings

- Commission F Open Symposium Nov 2010
- Commission F specialist Meeting on remote sensing
- AP-RASC09 (in addition for sponsorship "A")
- Climm'Diff 2009

Topic 10: Proposed meetings for next triennium

Action

1. Commission F Triennium Open Symposium (type B)
   Madhu Chandra proposed to organize it. The proposal was unanimously accepted.
   venue: Garmisch-Partenkirchen, Germany
   period: Nov 2010
2. Specialist meeting on remote sensing (type B)
   Proposal: No firm decision was reached. Bertram Arbesser-Rastburg and Roger Lang agreed to consider the possibility of hosting this meeting in tandem with other URSI-sponsored meetings organized by them.
   Venue: pending
   Period: pending

Members sited that conference may face stiff competition from IGARSS. This action continues!

Topic 11: Comm-F proposals for sessions at the next URSI GA in 2011

Action: Suggested (tentative) list of topics:

- Channel characterization
- Channel models
- GPR and UWB applications
- Terahertz propagation
- Propagation effects in GPS/GNSS
- UWB indoor propagation,
- Active and passive remote sensing systems
- SMOS Aquarius related topics
- Global observation of the earth surface
- Cryosphere and Arctic sphere
- Multiparameter radar applications
- Education in the area of remote sensing (e-learning)
- Propagation and RS of vegetation, moisture RS,
- Rain and the atmosphere
- Ocean surface RS
- Irregular terrains
- Open sessions 1 and 2
- Theoretical developments common to radiocomm and RS

Topic 12: Inter-commission working groups (C)

Action: The WGs automatically end at the GA and must be renewed by resolution

Working Groups suggested:

· The Group on Mitigation of Ionospheric and Tropospheric Effects on GNSS (Bertram Arbesser-Rastburg continues)

· Education and training in RS and related aspects on propagation (M. Chandra and Jean Isnard) to be linked to the activity on the proposed white paper (disaster management and remote sensing)

Topic 13: Representatives to other organizations

Action:

- SCOR: Scientific Committee on Ocean research (Delaware)
  The incoming vice-chair: D. Weissman
- IUCAF (Scientific Commmittee on Frequency Allocations for Radio Astronomy and Space Science)
  Steven Reising, Colorado State University, USA
- COSPAR: Committee on Space Research (Paris)
  Bertram Arbesser

Madhu requested to be kept informed

Topic 14: Publications and Publicity

Action:

a. Radio Science Bulletin
   Roger Lang, Madhu Chandra and Ian Glover agreed to serve as referees and facilitators

b. Information dissemination
   All commission members were requested to regularly visit the URSI webpage of Commission-F and to pass on their suggestions to Madhu Chandra.

Topic 15: Any other business

Action: All commission members were requested by Piotr Sobieski and Madhu Chandra to support commission activities even more strongly than in the past and to maintain close contact with the commission chair.

BUSINESS TRANSACTED BY COMMISSION G

Chair: Prof. Paul Cannon
Vice Chair: Dr. Michael Rietveld

1. Commission G Business Meeting 1

Monday 11 August 2008, 17.20h to 18.40 hrs
At least 34 were present (34 signed an attendance list)
Paul Cannon presided over the meeting with the following agenda:

1. In Memoriam and Introduction
2. Election of new Commission G Vice-Chair for 2008-2011.
3. Terms of reference
4. Commission G triennium report by Chair
5. Reports by working group chair
6. Publications
7. Comment on GA 2008 organization and programme
8. proposals for session at GA in 2011 (Mike Rietveld)
9. Resolutions

1. 1 In Memoriam
The business meeting commenced with a brief moment remembering past friends of Commission G:
· Jean-Paul Villain (France)
· A.P. Mitra (India)
· Pietro Dominici (Italy)
· Tor Hagfors (Norway)
· Ludmila Logvinova (Russia)
· Roy Piggott (UK)
· Paul Argo (USA)
· Others known personally

1.2 Election of new Commission G Vice-Chair for 2008-2011
Concerning the election for Vice-Chair it was explained
a. What the Commission G Vice-Chair duties are.
b. Who nominates the Vice-Chair candidates.
c. When were the nominations called.
d. How many candidates can there be.
e. Who votes for Vice-Chair candidates.
To date, 15 postal votes were cast. These and paper ballots from designated international commission delegates were counted by Mike Rietveld (VC) and Christian Hanuise (previous chair)

The candidates:
· Manuel Hernandez Pajares – Spain
· John Mathews – USA
· Jian Wu – China

The first two candidates introduced themselves in a 2-minute statement. Prof. Jian Wu explained in a letter to the Chairman and colleagues of Commission G that he could not attend the meeting due to the problem with obtaining the visa. John Mathews was the successful candidate.

1.3 URSI Commission G Terms of Reference
· The Commission deals with the study of the ionosphere in order to provide the broad understanding necessary to support space and ground based on radio systems.
· To achieve the objectives, the Commission cooperates with other Commissions, corresponding bodies of the ICSU family (UIGG, IAU, COSPAR, SCOSTEP, etc.) and other organizations (ITU, IEEE, etc.) Chair report is available on URSI Website.

The terms of reference of Commission G were reviewed and it was decided that no amendment was necessary.

1. 4 Commission G triennial report
Funding to Commission G
· €9000 have administered for the good of the community.
· €4500 was spent in supporting various meetings, typically at the €500 or €1000 level.
· €4500 has been used to support seven scientists, from a number of countries, to attend the general assembly this being the flagship meeting.
· $500 was also made available to support the attendance of non-US students of the meeting.
· The chair decided to make 5 awards, each of $1000 to those students who submitted to the Student Paper Competition. Other support was given to different schools, workshops, meetings, sessions, seminars, etc.

1.4.1 Website hosted by URSI: http://www.URSI.org/G/Homepage.htm
· Commission G also has an electronic mailing list hosted by Phil Wilkinson (URSI-commission-g@ips.gov.au)
· Chicago GA Programme- 250 papers at the GA. A centralized paper submission process was used.
· Christian Hanuise is the representative to the long range planning committee.
· Young scientists support (long standing)
· New scheme for support of the graduate students outside of the USA.
· Student paper competition.
· Strengthening of the Commissions that are not very active
· New topical initiatives and areas

1.4.2 Commission G papers which made it to the 10 finalists of the Student Paper competion
- Geometric Modulation: A new, more Effective Method of Steerable ELF/VLF Wave Generation with Continuous HF Heating of the Lower Ionosphere (*Commission G/H/E*), M. B. Cohen, U. S. Inan, Stanford University, Stanford, CA, United States
- Coordinated Analysis of delayed Sprites with High Speed Images and Remote Electromagnetic Fields (Commission E/G/H), J. Li, S. A. Cummer, Duke

University, Durham, NC, United States

- Demeter Observations of a Column of Intense upgoing ELF/VLF Radiation Excited by the HAARP HF Heater (Commission H/G), D. Piddyachiy[1], U. S. Inan[1], T. F. Bell[1], M. Parrot[2], N. G. Lehtinen[1], 1Stanford University, Stanford, CA, United States; 2CNRS, Orleans, France

Commission G has ~250 papers at the GA, an excellent turn out against a background of many other meetings being held this year.

Conclusion

- Commission G is in a pretty good shape
- Vice-Chair election Result: John Mathews (USA) has been elected the International Commission G Vice-Chair for 2008-2011
- Concern: Profile of URSI (squeezed by IEEE, COSPAR.)

1.4.3 New topical initiatives and areas

Canvassed the Commission G National Representatives: Identified important emerging issues in categories of "Applied" Science & Systems and "Pure" Science.

Applied:

Radar remote sensing from space and in space, High integrity GNSS navigation systems, and assimilative models of ionospheric density and Scintillation, and low frequency astronomy.

Pure:

Planetary ionospheres, Anthropogenic effects (ionospheric modification by HF heaters and climate change), plasmaspheric physics and models

As usual, significant opportunities or interaction exist with Commissions F, H, and J. This should flow through into session choice for 2011

1.5 Commission G Working Groups and Joint Working Groups

All Working Groups triennium reports were included in the Commission triennium report. These reports are the responsibility of the lead commission representative. A very brief verbal report was provided at the Business Meeting.

- *G.1. Ionosonde Network Advisory Group (INAG).* Chair: Terence. Bullet (USA), Vice-Chair: Lee-Anne McKinnell (South Afica), INAG Editor: P. Wilkinson (Australia) Recommend continuing with Lee-Anne McKinnell (SA) replacing Terence Bullet as Chair and Ivan Galkin replacing Lee-Anne McKinnell as Vice-Chair. Will propose a new data exchange format.
- *G.2. Studies of the Ionosphere Using Beacon Satellites.* Chair: R. Leitinger (Austria), Vice-Chairs: J.A. Klobuchar (USA; until October, 2004); P. Doherty (USA, since October, 2004) and P.V.S. Rama Rao (India). Recommend continuing with the same team. R. Leitinger was still unwell after a stroke, but is slowly recovering. The group wants 3 things: Meeting support, Student support for the meeting, and agreement to continue with current leadership.
- *G.3. Incoherent Scatter.* Chair: Chair: W. Swartz (USA), Vice-Chair: J.P. Thayer (USA). Recommend continuing with Ingemar Häggström (Sweden) as chair and Mary McCreadie (USA)
- *G.4. Ionospheric Research to Support Radio systems.* Chair: P. Wilkinson (Australia); Co-Chair: M. Angling (UK). Recommend disbanding because of a lack of interest. Reasons were too much overlap with other groups and too much commercial interest.. Some objection was voiced and will be discussed in WG on Thursday– see record of third business meeting.
- *GF. Middle atmosphere.* Co-Chair for Commission G: J. Röttger (Germany), Co-Chair for Com. F: C. H. Liu (China, SRS). Recommend continuing with the same officers.
- *FG: Atmospheric Remote Sensing using Satellite Navigation System.* Co-chair for Commission G: C. Mitchell (UK). Co-Chair for Commission F. Bertram Arbesser-Rastburg. Recommend continuing with the same officers.
- *Inter-commission Working Group on Solar Power Satellite.* Co-Chair for Commission G: M. Rietveld (Norway). Recommends replacing M. Rietveld with someone else.

1.6 Publications

The Chair, P. Cannon, on behalf of the Commission, thanked Mike Rietveld as the Commission G editor and Vice-Chair for Reviews of Radio Science, for his hard work. Commission G had two reviews and another paper accepted during the triennium which was slightly less than its quota.

- Space Weather Impacts of the Subauroral Polarization Streams by Anthea Coster and John Foster, RSB 321, June 2007
- The impact of high resolution radar on meteor studies: the EISCAT perspective by Asta Pellinen-Wannberg, Gudmund Wannberg, Johan Kero, Csilla Szasz and Assar Westman RSB no 324, March 2008.
- A collection of papers on ionospheric raytracing to remember the pioneering work of Jennifer Haselgrove. June 2008 of RSB.

John Mathews will be the Commission G editor for the Radio Science Bulletin. At http://www.ips.gov.au/IPSHosted/NCRS/reviews you can find the guides to the style and format used for the Radio Science Bulletin and specifically for the reviews of the RSB, as well as the check list for authors submitting a paper in final form for the bulletin.

1.7 Discussion on GA 2008 organisation and programme

Submission of abstracts. There was once again a general agreement on having a one-step only submission. People were generally satisfied with the present abstract submission software. A list of Commission G sessions of the GA 2008 is given in Appendix A.

1.8 Proposals for sessions in 2011

A call for proposals was made.

Proposed G-related sessions for the next GA 2011 include:

- Radar techniques
- Radio occultation
- Active experiments in plasmas

Proposed HG sessions:

- Modification of the ionosphere and magnetosphere (2 sessions)
- Dusty plasmas
- Electric field antennas in plasmas
- Ionospheric modifications from space
- Ionospheric effects of lightning
- Plasma irregularities and turbulence

Proposed GH sessions

- Radio Sounding Techniques for the Ionosphere and Magnetosphere

Proposed EGH sessions

- Terrestrial and planetary EM disturbances and effects
- Seismo-electromagnetics: lithosphere, atmosphere, ionosphere coupling
- VERSIM – ULF/ELF remote sensing of the ionosphere and magnetosphere

1.9 Resolutions

- COSPAR endorsed and adopted the new COSPAR International Reference Atmosphere (CIRA 08) COSPAR further invites
- URSI to review CIRA 08 during its assembly to be held in August 2008 and to approve and adopt CIRA 08 joinly with COSPAR
- CIRA 08 is anticipated to be published in late 2008 or early 2009 as a special issue of Adv. Space Res.
- The members of CIRA working group will take responsibility for the preparation of the individual chapters of the work, following approved guidelines.

2. Business Meeting 2: Joint between Commissions G and H

Wednesday, 13August 2008

Chairs: Paul Cannon (G) and Richard Horne (H)

About 70 people in attendance

2.1 Agenda

1. Introduction
2. Resolutions from board and impact on Commissions G and H
3. Reports by working group chairs
4. Commission G and H delegates to committees (updates)
5. First discussion on proposals for sessions in 2011 (Mike Rietveld and Yoshi Omura)

2.2 Resolutions

1. To create an inter-commission working group on Natural and Human-Induced Catastrophes and Disasters with the following objectives:
   - To study methods and propose strategies related to Communication systems to set up the time of and after disaster
   - To the use of remote sensing and other data for monitoring and alerting, describing the disturbed environment at the time of disaster and after it
   - To take into account the work of the ITU and other similar bodies
   - To provide support to initiatives taken on natural and human-induced catastrophes and disaster, particularly by developing countries (floods, earthquakes, space weather)

   There was a discussion, initiated by Franois Lefeuvre on the usefulness of radio techniques in the areas of floods, earthquakes, space weather. The EGH seismo-e/m working Group, and the Demeter spacecraft are relevant. Richard H and P Cannon will provide inputs.
2. To establish an inter-Commission WG on radio science services (RSS) with the mission:
   - In agreement with the IUSAF, to analyze and if needed, react to ITU recommendations and resolutions that may concern passive and active radio services
   - To inform the URSI commissions regarding the development of new communication systems, and to study with them potential consequences for specific passive and active radioscience services
   - To contribute to inter-union or/and inter-organization activities related to passive and active radio services
3. From the March 2009 issue of the Radio Science Bulletin onwards
   - URSI Radioscientists and officers no longer receive a free copy of the Radio Science Bulletin
   - A limited number of issues will be sent in bulk mailing to the academics (10 copies per dues category)
   - There will only be one such mailing per member committee
   - Those who wish to receive a printed version of the Radio Science Bulletin need to pay a subscription fee of 100 Euro per triennium (or 60 Euro on top of the registration fee at an URSI general assembly)
   - Libraries can take a subscription at the current rate of 50 Euro per year
4. It was recommended that URSI forms an inter-Commission Data Committee
   - To provide an oversight of URSI data interests
   - To provide an effective interface with other ICSU data communities including overarching groups such as GEOSS (Global Earth Observing System of Systems). And the proposed WDS, and the Committee on Data for Science Technology (CODATA) which URSI recently joined
   - That the initial membership include the current WDC, FASS and ISES representatives, together with representatives proposed by the Commissions
   - That the Data Committee will provide regular reports to the URSI Board and Council and respond to

questions from the commissions, the Board and the Council
- That the Data Committee will develop its own terms of reference and propose these to the Board for further development prior to the next general assembly in 2011

Several people felt this was important, for example to address the problem of long term data storage (Wes Swarz). Amongst others, interested were Dieter Bilitza/ Phil Wilkinson/ Rod Redmon.

2.3 Working Group Reports

- GH: Active experiments in plasmas - Co-Chairs
  For commission G: K. Groves (UK)
  For commission H: Bo Thide (Sweden), Recommend continuing with the same officers
- EGH: Seismo Electromagnetics (Lithosphere-Atmosphere-Ionosphere-Coupling) Co-Chairs
  For commission G: S. Pulinets (Russia)
  For commission H: M. Parrot (France), Recommend continuing with the same officers
- Inter-Commission working group on solar power satellites
  Chair: Hiroshi Matsumoto (Japan)
  Co-Chair for commission G: M. Rietveld (Norway)
  Co-Chair for commission H: N. Shinohara (Japan), Recommends replacing M. Rietveld with K. Schlegel (Germany)
- URSI/IAGA VLF/ELF remote sensing of the ionosphere and magnetosphere (VERSIM) Co-Chair
  For commission H/G: M. Janos Lichtenberger (Hungary), Recommend continuing with the same officers

The working group report appears in the Commission H report

3. Commission G Business Meeting 3

Friday, 15August 2008, 17:20 to 18:30 hrs
Chair: Michael Rietveld and Vice-Chair: John Mathews
Approximately 38 people were in attendance.

Agenda

1. Introduction by outgoing Chair Paul Cannon
2. The next GA, in 2011, will be held in Istanbul, Turkey
3. Reports from Working Group business meeting earlier in the week (Wednesday, 13 August 2008)
   - International committee on global navigation satellite systems
4. Commission G resolutions
   - Ionosonde data exchange
   - COSPAR international reference Ionosphere
5. Commission G: 2011 assembly
   - Commission G tutorial lecture for 2011
   - Sessions for GA 2011
   - Suggested general lectures for 2011
6. Publications J. Mathews
7. Review of GA 2008
8. White papers

3.1 Opening Comments

The outgoing Chair, Paul Cannon, thanked the Commission for the support they have given to him during his tenure and especially for the assistance given by the incoming Chair, Michael Rietveld. The incoming Chair, Michael Rietveld, then acknowledged the work put by Paul Cannon and thanked him for his efforts and expressed the pleasure he had working with him, as well as expressing his pleasure at being the new Chair. Michael Rietveld then took over chairing the meeting and the Commission.

3. 2 The next GA 2011: Commission G sessions

Istanbul (Turkey) has been selected for 2011 General Assembly.
Working Group 4 will remain as a working group through the Radio Techniques Conference in Edinburgh next year

3.3 Working Groups

G1: Ionosonde Network Advisory Group
Chair: L-A McKinnell (South Africa), Vice-Chair: Ivan Galkin (USA), INAG Editor: P. Wilkinson (Australia)
G.2. Studies of the Ionosphere using Beacon Satellites
Chair: R. Leitinger (Austria), Vice-Chairs: P. Doherty (USA), P.V.S. Rama Rao (India) and M Hernandez-Pajares (Spain)
G.3 Incoherent Scatter
Chair: W. I Haggstrom (Sweden), Vice-Chair: Mary McCready (USA)
G.4 Ionospheric Research to Support Radio Systems
Chair: M. Angling (United Kingdom), Vice-Chair: Denis Knepp (USA)
GF Middle Atmosphere
Co-Chair for Commission G: J. Röttger (Germany), Co-Chair for Commission F: C.H. Liu (China, SRS)
GH1 Active experiments in Space Plasmas
Co-Chair for Commission G: K Groves (USA), Co-Chair for Commission H: B. Thide (Sweden)
URSI-COSPAR on International Reference Ionosphere (IRI)
Chair : B.W. Reinisch (USA), Vice Chair for COSPAR : Martin Friedrich (Austria), Vice Chair for URSI: Lida Triskova (Czech Republic); Secretary: D. Bilitza (USA),
FG: Atmospheric Remote Sensing using Satellite Navigation System
Co-chair for Commission G: C. Mitchell (United Kingdom)
EGH: Seismo Electromagnetics
for Commission G: S. Pulinets (Russia)
Inter-commission Working Group on Solar Power Satellite
Co-Chair for Commission G: K Schlegel (Germany)
URSI/IAGA VLF/ELF remote Sensing of the Ionosphere and Magnetosphere (VERSIM)
Co-Chair for Commission H and G: M. Parrot (France)

3.4 Commission G Resolutions

The following two resolutions from Commission G were presented, explained and passed unanimously.

Commission G Resolution: CIRA08

Considering

The development of the new COSPAR International Reference Atmosphere (CIRA08),

and the importance of CIRA to URSI Commission G related activities, especially in regard to the International Reference ionosphere (IRI)

Resolves

To encourage COSPAR to continue with the development of the model

(At COSPAR 2008 it was decided to publish CIRA08 as a stand-alone book of Adv. Space Res, with chapters dedicated to:

- four primary models of JB2008, NRLMSISE-00, HWM07, and GRAM-07 developed by AFSPC, NRL, and MSFC respectively,
- energy and momentum inputs from solar, geomagnetic, dynamic and advective sources,
- middle atmosphere composition and structure, especially the minor (metal) species,
- a summary of physics-based and data assimilative models,
- in-progress issues including,
- drag coefficients,
- trends such as thermospheric cooling,
- error analysis,
- appendices including data output examples and reference atmospheres.)

Commission G Resolution: Adoption of a New Ionosonde Data Exchange Format

Considering:

That the capabilities of ionosondes have grown in the last decade.

And that the numbers of new data elements have increased while retaining historical data elements.

And that advances in the state of the art in information technology have occurred which make practical the use of extensible, self defining formats.

And that a new data format, SAO-XML, has been developed, documented, tested and reviewed.

And that the members of the Ionosonde Network Advisory Group (INAG), Commission G Working Group 1 have requested the recognition of SAO-XML as a new standard format for ionosonde data exchange.

Recommends:

That the data format known as SAO-XML be recognized as a format for the exchange of ionogram scaled characteristics and derived data elements from ionosondes.

3.5 The following topics for the GA 2011 sessions were proposed

- *Tutorial topics*
  Satellite missions to observe lightning and gamma-ray flashes
  ISR modeling
  Equatorial Plasma Bubbles
  Solar maximum effects on radio systems
- *General Lectures*
  Meteor echoes
  Sprites, lightning, x-rays
- *Sessions*
  1. Practical applications and techniques for the use of ionosonde data (Lee-Ann McKinnell, Paul Cannon)
  2. Distributed observatories for space weather studies (A. Coster, L. McKinnel, P. Doherty)
  3. Ionospheric research for Radio Systems Support (I. Stanislawska, H.S. Strangeway)
  4. Communications and radar systems (waveforms, frequency management, raytracing), Paul Cannon
  5. Irregularities and Scintillations, new measurement techniques and results
  6. New Science Initiatives Using Beacon Satellites: Studies over the next few years will increase with the new satellite missions of COSMIC, C/NOFS and others. Perhaps we can consider a session focused on these topics. Proposed chairs: someone from COSMIC and someone from C/NOFS.
  7. Measuring and Modeling the Ionospheric Electron Density Profile (D. Bilitza, B. Zolesi, B. Reinisch)
  8. CAWSES-2 Ionospheric Campaigns and Results (C. Hanuise and J. Thayer)
  9. Coordinated studies with multiple incoherent scatter radars (I. McCrea and A. Strømme). covering radar as well as satellite (Cluster, Themis ...) data sets.
  10. Technical developments for incoherent scatter radars (Mike Nicholls and Assar Westman or Ingemar Häggstrðm)

The following sessions with other commissions have been variously proposed:

1. GH Ionospheric modification (K. Groves (G) and M. Sulzer or R. Moore suggested (H))
2. HG Space-borne sounding and Remote Sensing of Structures in the Plasmasphere (active & passive) (B. Reinisch (G), R. Benson (H)) Planetary, lunar surface, subsurface and ionospheric sounding
3. HG Active experiments in Plasmas with Electric Antennas and other means (G. James, V. Sonwalker (H))
4. GH Ionospheric effects of Lightning (M. Fullerkrug (G) and U. Inan (H))
5. HABCDEFGK Solar power satellites ((G), K. Hashimoto (H))
6. J/G Ionospheric Calibration for Radio Astronomy ((J) and C. Mitchell (G))
7. GHJ Turbulence and vorticity (suggested by B. Thide) (G)
8. HGE Electromagnetic effects in Lithosphere-Atmosphere-Ionosphere Coupling (S. Pulinets, M. Parrot)
9. CFG Radiolocation Covers all aspects (applications, technology) of radiolocation (M. Warrington)
10. C/G MIMO at HF (H. Strangeways)

3.6 Publications
The incoming Vice-Chair, John Mathews was confirmed as the Commission G editor for the new Radio Science Bulletin, incorporating the Review of Radio science. Contributions are requested.

3.7 Comments on 2008 GA
The General Assembly was considered quite successful for Commission G based on the number and variety of papers and attendance at sessions
Some comments were:
- Paper quantity at registration about right
- Laser pointers really good.
- Bags: some find them unnecessary, others don't
- Print Business meetings time/place in programme
- Poster board size excellent, time scheduled bad (should be >1 day)
- Better web page conference details just before the meeting
- Biscuits, (diet)-softdrinks at coffee breaks
- Wireless microphones needed
- Internet access should be better in conference rooms
- Noisy room (Grand E): Sounds like hotel deliveries and other work behind the partition walls.

3.8 White Papers
. Solar power satellite (issued)
. Wireless effects on health (being drafted)
. Suggested Commission G -led "Space weather effects on technology" but little enthusiasm from the meeting

Appendix A: Sessions held at the 2008 General Assembly
G01: Open Session and Latest Results
7 oral plus 20 posters
Conveners: C. Hanuise, A. Coster
G02: Density Profiling and Models
10 oral plus 16 posters
Conveners: B. Reinisch, D. Bilitza, B. Zolesi
G03: Irregularities and Scintillation
11 oral plus 34 posters
Conveners: P. Doherty, A. Bhattacharya, E. de Paula
HG1a and b: Wave-particle Interactions and Radiation Belt Remediation
15 oral plus 11 posters
Conveners: J. Albert, G. Ganguli, K. Groves
G04a&b: Assimilation and Imaging of the Ionosphere and Plasmasphere
12 oral plus 7 posters
Conveners: G. Bust,N. Jakowski, M. Codrescu
GHE: Modification of the Ionosphere and Magnetosphere
7 oral plus 21 posters
Conveners: K. Groves, Y. Ruzhin, M. Kosch, O. A. Molchanov
FG: Mitigation of Ionospheric and Tropospheric Effects in Precision GNSS.
7 oral plus posters
Conveners: B. Arbesser-Rastburg, M. Hernández-Pajares
GF: Radio Occultation – Techniques, Validation, Science and Applications
10 oral plus 4 posters
Conveners: C. Mitchell, C.-H. Liu, T. Schueler
EGH: Terrestrial and Planetary Electromagnetic Disturbances and Effects
10 Oral plus posters
Conveners: M. Hayakawa, C. Price, M. Füllekrug
GH: Radio Sounding Techniques for the Ionosphere and Magnetosphere.
11 oral plus 7 posters
Conveners: L.-A. McKinnell, G. James
HG2: Dusty Plasmas
6 oral plus 4 posters
Conveners: M. Rosenberg, P. Bernhardt
JG: Low Frequency Radio Astronomy and the Ionosphere
6 oral plus posters
Conveners: G. de Bruyn, P. Rao, B. Junor, bjunor@lanl.gov
G05a&b and c: Radar Studies I
21 oral plus 30 posters
Conveners: W. Swartz, M. Lester, J. Chau
HGE: Seismo-electromagnetics
10 oral plus 27 posters
Conveners: M. Parrot, S. Pulinets, O. Molchanov
G06: Improving Radio Systems through Ionospheric Radio Science
7 oral plus 8 posters
Conveners: M. J. Angling, C. Coleman, A. Bourdillon
HBDGJK: Solar Power Satellites
7 oral plus 4 posters
Conveners: K. Hashimoto, R. Dhillon, W. van Driel, R. J. Pogorzelski

BUSINESS TRANSACTED BY COMMISSION J

Chair: Prof. R.T. Schilizzi
Vice-Chair: Prof. S. Ananthakrishnan

Commission J meetings were held by Prof.Richard Schilizzi on the following two days:

Meeting 1: Monday, August 11, 17:20 – 18:40
Meeting 2: Wednesday, August 13, 17:20-18:40
Meeting 3: Friday, August 15, 17:20-19:00

1. Business Session I

1.1 URSI Awards
(i) Jack Welch
Balthasar van der Pol Gold Medal
Citation: "Pioneer of millimeter wavelength interferometry to investigate astronomical objects ranging from solar system planets to galaxies at the edge of the Universe with spectral and angular resolution"

(ii) Alan Rogers
John Howard Dellinger Gold Medal
Citation: “For his outstanding contributions to instrumentation in radio astronomy and its use to make fundamental discoveries about interstellar masers, superluminal expansion of quasars, deuterium abundance in the galaxy, and plate tectonics”

Commission J members congratulated both members on their well deserved awards.

1.2 Election of Vice-Chair
Candidates
(i) Don Backer – USA
(ii) Justin Jonas – South Africa
(iii) Marat Mingaliev – Russia
(iv) Shang-Cai-Shi - China

Votes received from:
Australia, Canada, China, Czech Republic, Finland, France, Greece, Hungary, India, Israel, Netherlands, New Zealand, Poland, Russia, South Africa, Sweden, Taiwan ROC, USA

Dr. Don Backer of USA was elected as Vice-Chair.

1.3 Commission J Budget, report on 2005-8 triennium
A. Budget 2005-2008 (Commission J activities):€11000
Expenditure 2005-2008 for Commission J activities

i) Astrophysics in the LOFAR era” Emmen Netherlands, April 07	€3000
ii) From Planets to Dark Energy: the Modern Radio Universe”, Manchester, UK, Oct. 2007	€4000
iii) Travel grants to URSI GA Bob Frater (special invitation) Jayanta Roy (India) Peeyush Prasad (India)	€3450
TOTAL	€10450
Balance carried forward	€550

B. Extra grant of $5000 for travel grants for Young Radio Scientists to GA2008
$1000 each to J.L. Du (China), Stefan Wijnholds (NL), Peter McMahon (SA)
$500 each to A. Parsons, R. Shannon, B. Barrott, N. Paravastu (all USA)

TOTAL $5000

1.4 Discussion of issues arising from 10 August meeting of the URSI Council
Reactions to White paper on Solar Power Satellite system Many members expressed their concern about the possible implication of the SPS to radio astronomy observations.

1.5 Resolutions discussed in the Council
Item 1: Inter-Commission WG on Natural and Human-Induced Catastrophes and Disasters: Coronal Mass Ejections (with Comm. H). A discussion on how the CME propagation could be observed using radio astronomy techniques was done.
Item 3: Inter-Commission WG on Radio Science Services: Work with IUCAF.
Forum on Radio Science and Telecommunications.
Item 5: Change name of GA to “URSI General Assembly and Scientific Symposium”
Item 8: Inter-Commission Data Commission: ICSU initiative.

Comm J representative should be an expert on the Virtual Observatory.

1.6 IUCAF
A presentation by Wim van Driel, IUCAF Chairman on its activities during the past 3 years. The WRC 2007 conference was used by IUCAF to bring more protection to some of the radio astronomy bands.

1.7 Terms of Reference for Commission J
Changes were introduced in the terms of reference for Commission J, in keeping with the changing times as well as to reflect the changing nature of radio astronomical observations.
RADIO ASTRONOMY (including remote sensing of celestial objects)
- The activities of the Commission are concerned with
  1) observation and interpretation from the early universe to the present epoch and
  2) radio reflections from solar system bodies
- Emphasis is placed on:
  The promotion of science-driven techniques for making radio-astronomical observations and data analysis,
  Support of activities to protect radio-astronomical observations from harmful interference.

1.8 Other topics
Triennium report, Posters, Commission J Resolution, Editor RSB, GA2011, visit to Wheaton. The Chairman noted, as part of the record, that Prof.A.van Ardenne gave the Commission J tutorial and Prof. Jim Cordes gave one of the General lectures.

2. Business Session 2

2.1 Report on 12 August URSI Council meeting

2.2 Commission J Resolutions

2.3 Editor for Radio Science Reviews, topics for the next triennium.

2.4 Report from GVWG (Jon Romney)
- continuation of GVWG was emphasised. A sub-committee was formed to elect the next Chair of GVWG.

2.5 URSI Long Range Planning

2.6 Other topics: Young Scientist Awards, Student Prizes
– The need to strengthen: the YS programme was emphasised.

2.7 Presentation of Grote Reber Gold Medal to Sandy Weinreb was highly appreciated.

3. Business Session 3

Chairman: Prof.R.Schilizzi (first half) / Prof. S.Ananthakrishnan (second half)
Vice-Chairman: Prof. Don Backer

3.1 Report on 14 August URSI Council meeting

3.2 Terms of Reference for Commission J

3.3 URSI Recommendation on the SKA

3.4 GVWG

3.5 URSI Long Range Plan/Emerging issues in CommissionJ.

3.6 General Assembly 2011, Commission J Program
Suggestions:

(a) Low Frequency Radio Astronomy;
(LOFAR, LWA, MWA, GMRT, any other)
(b) SKA –Technology Development;
(c) ALMA - mm and sub-mm science & technology;
(d) Signal Processing, Calibration and Imaging in radio astronomy;
(e) Sun and solar system science;
(f) Space and Moon 'Science & Technology';
(g) Observatory reports – same format ?;
(h) Joint sessions ? Suggestions? ;
(j) Splinter/WG meetings during lunch time;
(k) New Observations and results.

3.7 Budget 2008-11 was briefly discussed.

3.8 Topics for Radio Science Bulletin 2008-2011.
a)"Phased arrays in Radio Astronomy", A. van Ardenne (Commission J Tutorial, 2008), in preparation.
b) "Paths to Discovery in Radio Astronomy", R. D. Ekers (in preparation?)
c) "Calibration of High Frequency Telescopes" TBD
Editor: Dr. Richard Strom has agreed to take it up.

3.9 Meetings to be supported by Comm. J, 2008-11 – a list to be made.

3.10 Communication with Comm. J members – the existing email list needs to be improved.

Conferences

CONFERENCE REPORT

Vth International Workshop on Electromagnetic Wave Scattering - EWS'2008 Workshop

Akdeniz University, Antalya, Turkey, 22 - 25 October 2008

The Fifth International Workshop on Electromagnetic Wave Scattering, EWS'2008 was organized at Akdeniz University, Antalya, Turkey on October 22-25, 2008. The members of the organization Committee were Professors A. H. Serbest, A. Altintas, Gokhan Cinar, I. H. Tayyar, Selcuk Helhel, Sukru Ozen and Omer Colak. The aim of the workshop was to bring together scientists all around the world and give them an opportunity to discuss EWS topics in a wide range of time, giving 45 minutes for each presentation.

The official opening was done by Prof. A. Hamit Serbest of Cukurova University, Chair of URSI-Turkey National Committee. In the technical program, there were more than 60 participants with 31 presentations from different countries all over the world. The proceedings is available at the URSI Turkey web site at: http://www.ursi.org.tr/2008-EWS/ews_2008.pdf TUBITAK (The Scientific and Technological Research Council of Turkey) supported financially the young researchers participating from universities all around Turkey.

URSI Turkey National Committte is very much thankful to Akdeniz University, Gebze Institute of Technology and TUBITAK (The Scientific and Technological Research Council of Turkey) who supported financially the young researchers participating from universities all around Turkey. Without their generous help, the workshop would not have been that successful.

CONFERENCE ANNOUNCEMENTS

EMC Europe Workshop - Materials in EMC Applications

Athens, Greece, 11 - 12 June 2009

Scope

In recent years, the need to make more compact designs and to operate at increasingly higher frequencies has required innovations in design and a more intelligent use of materials. Examples are the use of carbon fibre composites (CFCs) in vehicle manufacture in order to reduce weight and the impact of this development on reduced shielding and electromagnetic design in general. At the other end of the scale, meta- and nano- materials are discussed as possible candidates for reducing cross-talk in compact designs. New absorbing materials are being developed for use in EMC applications. The scope of this Workshop encompasses all these areas. The key criterion for inclusion in the Workshop is that an EMC application is addressed. Abstracts should therefore make clear the EMC relevance of the contribution.

Topics

- Left Hand Materials (LHM) for shielding and absorption
- Use of LHM to achieve higher sensitivity of small probes and antennas
- Nanotechnology application in the EMC domain
- Other new technologies for shielding and absorption
- Ferrites in high frequency applications
- Ferrites for low frequency and high-current applications
- Textiles, sheets and films for shielding
- Conductive textiles
- Frequency dependent surfaces
- Electromagnetic properties of composite materials
- Material and component characterization and measurement methods
- Material and component modelling and simulation techniques

Workshop Chair & Vice Chair

The Workshop is chaired by Prof. N. Uzunoglu (Greece) and co-chaired by Prof. C. Christopoulos (UK).

Publications

The Workshop Proceedings will be published in IEEE Xplore!

Contact

Prof. Nikolaos Uzunoglu
Dr. Irene Karanasiou
National Technical Univ. of Athens
School of Electr. & Comp. Engineering
9, Iroon Polytechneiou
Zografou Campus
15780, Athens, GREECE
email: emceurope2009@iccs.gr

14th International EISCAT Workshop

Tromsø, Norway, 3 - 7 August 2009

The 14th International EISCAT Workshop will take place in Tromsø, Norway, between August 3 and 7, 2009. This incoherent-scatter radar workshop will cover results from areas including the International Polar Year, the middle atmosphere, solar wind and magnetosphere, auroral phenomena/ionosphere and thermosphere, structure and dynamics of the polar cap and cusp, meteors, and ionospheric heating. We also welcome abstracts on space weather (including space debris). In addition to scientific results, there will be sessions on new radar plans and techniques (e.g. EISCAT_3D, AMISR, and the new Antarctic radar). Oral or poster contributions are welcome. The abstract and registration deadline is **May 15, 2009**.

The venue is the Rica Ishavshotel, situated on the water's edge in the colourful seaport and university city of Tromsø. More details about the workshop can be found at http://uit.no/fysikk/eiscat2009ws/.

META'10
2nd International Conference on Photonic Crystals and Plasmonics

Cairo, Egypt, 22 - 25 February 2010

Scope

Following the big success of META'08 in Marrakesh, we are pleased to announce the next conference META'10 to be held in Cairo, Egypt on 22-25 February, 2010.

META'10 will cover the entire scope of complex electromagnetic materials, including metamaterials, photonic crystals and plasmonics. Special attention will be given to applications of these innovative materials in optical communication systems, antennas, high-speed circuits, optical sensing, nanoscale imaging, cloaking, biology and medicine,...

The program will include : Keynote lectures, Invited talks, Contributed oral and poster presentations, Interactive round tables.

Topics

Topics of the conference will include, but are not limited to: (The updated list is available on the conference website)

- Optical and microwave advanced materials: technologies and applications
- Modeling, fabrication and characterization of complex materials and structures
- Electromagnetic properties of metamaterials, photonic and plasmonic materials, subwavelength apertures, frequency selective surfaces, high impedance structures and novel composites with unusual electromagnetic properties (chiral, bianisotropic,…).
- Fundamental and applied aspects of waves in structured, periodic and disordered complex materials.

Important dates

January 8, 2010 : Deadline for submission of final manuscript and early registration
November 6, 2009: Notification of acceptance
October 9, 2009: Deadline for submission of abstracts
June 15, 2009: Proposals for special sessions and tutorials

Authors are strongly recommended to use the on-line submission system to submit their abstracts.

The paper format and submission guidelines can be found on the conference website.

Contact

META'10 secretariat
Laboratoire de Génie Electrique de Paris
LGEP-SUPELEC
Plateau de Moulon
91192 Gif-sur-Yvette Cedex
France

Tel.: +33 1 69851660
Fax: +33 1 69418318
Web site: http://www.meta10.lgep.supelec.fr
E-mail: meta10@lgep.supelec.fr

URSI CONFERENCE CALENDAR

URSI cannot be held responsible for any errors contained in this list of meetings.

May 2009

MST 12 - 12th Workshop on Technical and Scientific Aspects of MST Radar
London, Ontario, Canada, 17-23 May 2009
Contact: Wayne Hocking and Toshitaka Tsuda, Co-chairs, MST workshop series, Web: http://www.mst12.com/

12th Workshop on the Physics of Dusty Plasmas
Boulder, CO, USA, 18-20 May 2009
Contact: Dr. Zoltan Sternovsky, Laboratory for Atmospheric and Space Physics, UCB 392, Boulder, CO 80309-0392, Fax: +1 303 492 0642, E-mail: zoltan.sternovsky@colorado.edu, Web: http://wpdp.colorado.edu/index.php

URBAN 2009 - Data fusion and Remote Sensing in Urban areas
Shanghai, China, 20-22 May 2009
Contact : Shanghai Association for Science and Technology (SAST), No.47 Nanchang Road, Shanghai 200020, China (SAST), Fax: 86-21-6327 1590, E-mail: urban-urs2009@163.com, Web: http://www.urban-remote-sensing-2009.org.cn, Web: http://www.mst12.com/

June 2009

IHY Africa / SCINDA 2009 Workshop
Livingstone, Zambia, 7-12 June 2009
Contact: Dr. Lee-Anne McKinnell, Space Physics Group, Hermanus Magnetic Observatory, Dept of Physics and Electronics, Rhodes University, P O Box 94, Grahamstown 6139, South Africa, Email : L.McKinnell@ru.ac.za, Web: http://www.unza.zm/ihyafrica2009/ihy.htm

EMC Europe Workshop - Materials in EMC Applications
Athens, Greece, 11 - 12 June 2009
cf. Announcement in the Radio Science Bulletin of March 2009, p. 64.
Contact : Prof. Nikolaos Uzunoglu & Dr. Irene Karanasiou, National Technical Univ. of Athens, School of Electr. & Comp. Engineering, 9, Iroon Polytechneiou, Zografou Campus, 15780 Athens, Greece, E-mail: emceurope@iccs.gr

EMC 2009 - VIII International Symposium and Exhibition on Electromagnetic Compatibility and Electromagnetic Ecology
St. Petersburg, Russia, 16-19 June 2009
Contact : St.Petersburg State Electrotechnical University "LETI" , 5, Prof. Popov Street, St. Petersburg, 197376, Russia Underground Station "PETROGRADSKAYA", Fax: +7 812 234-46-81, E-mail: discone@mail.wplus.net, Web: http://www.eltech.ru/emc

ISTET-09 - International Symposium on Theoretical Electrical Engineering
Luebeck, Germany, 22-24 June 2009
cf. Announcement in the Radio Science Bulletin of December 2008, p. 72.
Contact: Ludger Klinkenbusch, E-mail: info@istet09.de, Web: www.istet09.de

July 2009

EMC'09 - 2009 International Symposium on Electromagnetic Compatibility, Kyoto
Kyoto, Japan, 20-24 July 2009
Contact: Prof. R. Koga, Dept. of Communication Network Engineering, Okayama University, Tsushima, Okayama, 700-8530, Japan, Fax +81 86-251-8136, E-mail: emc09@is.takushoku-u.ac.jp, Web: http://www.ieice.org/emc09/contacts.html

August 2009

14th International EISCAT Workshop
Tromsø, Norway, 3 - 7 August 2009
cf. Announcement in the Radio Science Bulletin of March 2009, p. 65.
Contact : Web : http://uit.no/fysikk/eiscat2009ws/

September 2009

Metamaterials 2009
London, UK, 1-4 September 2009
Contact: Dr. Richard W. Ziolkowski, E-mail: ziolkowski@ece.arizona.edu, Web: http://congress2009.metamorphose-vi.org/

ICEAA'09 - International Conference on Electromagnetics in Advanced Applications
Turin, Italy, 14-18 September 2009
Contact: ICEAA 07, Politecnico di Torino , Corso Duca degli Abruzzi 24 , 10129 Torino, Italy, Fax: +39-011-564-5199, e-mail: gspinasanta@corep.it, Web: http://www.iceaa.net/

October 2009

International Conference on Radar
Bordeaux, France, 12-16 October 2009
Contact: SEE / CONGRESS DEPARTMENT, Béatrice Valdayron - Valérie Alidor - Caroline Zago - Morgane Melou, Fax: + 33 (0)1 56 90 37 08, E-mail : radar2009@see.asso.fr , Web: http://www.radar2009.org

February 2010

8th International Nonlinear Waves Workshop
La Jolla, CA, USA, February 2010
Contact: William E. Amatucci, Plasma Physics Division, Code 6755, Naval Research Laboratory, Washington, DC 20375, USA, Fax : 202-767-3553, E-mail : bill.amatucci@nrl.navy.mil

META '10 - Second International Conference on Metamaterials, Photonic Crystals and Plasmonics
Cairo, Egypt, 22-25 February 2010
cf. Announcement in the Radio Science Bulletin of March 2009, p. 65.
Contact: Dr. Said Zouhdi, Laboratoire de Génie Electrique de paris, LGEP-Supélec, Plateau de Moulon, 91192 Gif-sur-Yvette Cedex, France, Fax+33 1 69 418318, E-mail: said.zouhdi@supelec.fr, Web: http://meta10.lgep.supelec.fr

April 2010

AP-EMC 2010 - Asia-Pacific EMC Symposium
Beijing, China, 12-16 April 2010
Contact: Web: http://www.apemc2010.org

July 2010

STP-12 SCOSTEP symposium
Berlin, Germany, 10-16 July 2010
Web: http://www.iap-kborn.de/SCOSTEP2010/ - SCOSTEP= Scientific Committee on Solar-Terrestrial Physics

COSPAR 2010 - 38th Scientific Assembly of the Committee on Space Research (COSPAR) and Associated Events
Bremen, Germany, 18 - 25 July 2010
cf. Announcement in the Radio Science Bulletin of December 2008, p. 73.
Contact: COSPAR Secretariat, c/o CNES, 2 place Maurice Quentin, 75039 Paris Cedex 01, France, Fax: +33 1 44 76 74 37, E-mail: cospar@cosparhq.cnes.fr, Web: http://www.cospar2010.org/ or http://www.cospar-assembly.org

August 2010

EMTS 2010 - International Symposium on Electromagnetic Theory (Commission B Open Symposium)
Berlin, Germany, 16-19 August 2010
Contact: EMTS 2010, Prof. Karl J. Langenberg, Universität Kassel, D-34109 Kassel, Germany, E-mail: info@emts2010.de , Web: http://www.emts2010.de

September 2010

AP-RASC - 2010 Asia-Pacific Radio Science Conference
Toyama, Japan, 22-25 September 2010
Contact: Prof. K. Kobayashi, Vice President for International Affairs, Chuo University, 1-13-27 Kasuga, Bunkyo-ku, Tokyo 112-8551, JAPAN, Fax: +81-3-3817-1847, E-mail: kazuya@tamacc.chuo-u.ac.jp

An up-to-date version of this Conference Calendar, with links to various conference web sites can be found at www.ursi.org/Calendar of supported meetings

News from the URSI Community

BOOK PUBLISHED BY URSI RADIOSCIENTISTS

Midlatitude Ionospheric Dynamics and Disturbances

Edited by Paul M. Kintner Jr., Anthea J. Coster, Tim Fuller-Rowell, Anthony J. Mannucci, Michael Mendillo, and Roderick Heelis; Washington, DC, American Geophysical Union, (Geophysical Monograph Series, Volume 181), 2008, 372 pp., ISBN 978-085790-446-7.

About this Book

Filling the need for a 20-year lag in substantial consideration of the mid-latitude ionosphere, this volume focuses on work that takes advantage of GPS and UV imaging from satellites over the past decade, two methods that have profoundly transformed our understanding of this stratum of the atmosphere. Its interdisciplinary content brings together researchers in the solar wind, magnetosphere, ionosphere, thermosphere, polar and equatorial ionospheres, and space weather. Modeling and assimilative imaging of the ionosphere and thermosphere show for the first time the complex and global impact of mid-latitude ionospheric storms.

This book was inspired by the Chapman Conference of the same name, held in January 2007.

Table of Contents

Recent Results

- Sources of *F*-Region Height Changes During Geomagnetic Storms at Mid Latitudes
- Neutral Composition and Density Effects in the October-November 2003 Magnetic Storms
- Optical and Radio Observations and AMIE/TIEGCM Modeling of Nighttime Traveling Ionospheric Disturbances at Midlatitudes During Geomagnetic Storms

Section IV: Ionospheric Gradients, Irregularities, and User Needs

- A Digest of Electrodynamic Coupling and Layer Instabilities in the Nighttime Midlatitude Ionosphere
- Irregularities Within Subauroral Polarization Stream-Related Troughs and GPS Radio Interference at Midlatitudes
- DEMETER Satellite Observations of Plasma Irregularities in the Topside Ionosphere at Low, Middle, and Sub-Auroral Latitudes and Their Dependence on Magnetic Storms
- Optical and Radio Observations of Structure in the Midlatitude Ionosphere: Midlatitude Ionospheric Dynamics and Disturbances

Section V: Experimental Methods and New Techniques

- Global-Scale Observations of the Limb and Disk (GOLD): New Observing Capabilities for the Ionosphere-Thermosphere

IN MEMORIAM

Helmut Kopka
1932 - 2009

Helmut Kopka, chief designer of the ionospheric heating facility near Tromsø, and author of books on LaTeX, passed away after a short illness on January 7, 2009. He was born in Dortmund, Germany, in 1932.

Helmut Kopka was a remarkable person and very talented in several areas. After completing his physics "Diplom" in fluid dynamics in Göttingen, he came to the Max-Planck-Institut für Aeronomie in Lindau (am Harz) in 1963. He brought with him excellent knowledge of computing, at a time when high-level computer languages did not exist. As his later work for the ionospheric-heating project showed, his knowledge went into great depth. He used numerical HF ray tracing to study ionospheric wave propagation at a time when this was very new. However, his true passion during these early years in Lindau was politics. He was instrumental in getting a workers' council established, against the will of the then director, and was active in the central workers' council of the Max-Planck Society, as well as in local politics. For several years, he served as Mayor of his village, and he even considered going into state politics.

The fact that he did not enter the state parliament had the positive effect that he could put more free energy into his work at the Institute. It was just the time – namely, 1974 – when a team was being recruited for a new project called Heating. This was a very powerful shortwave transmitter, designed to perturb and heat electrons in the ionosphere for active experiments in ionospheric and plasma physics. This facility was to be situated next to the new EISCAT incoherent-scatter radars, near Tromsø in northern Norway. Together with Peter Stubbe, Helmut was to lead the project. His first achievement was to use his political skills to arrange a financing concept among the three parties: MPG (Max-Planck Society), MPAe (Max-Planck-Institut für Aeronomie), and the DFG (German Research foundation). The MPG and DFG supplied two million German Marks each, while MPAe would pay for the salaries, travel, and running costs. Helmut's second achievement was to create a technical design that would satisfy the scientific requirements as well as the budgetary constraints. It was his trust in the exact validity of Maxwell's equations that gave him the confidence to design an antenna and transmission-line system that could be realized within the modest budget available. He did this using his physics, mathematics, and computing skills, without any previous experience and without the involvement of specialized companies or the use of commercial components: a tremendous achievement, indeed.

Helmut needed a challenge in his work, and this disappeared for him as the heating facility began to operate very reliably, after the few initial teething problems. He had wanted to write a text-processing program in his spare time.

When he learned of Donald Knuth's TeX program, he stopped his own efforts, and acquired an in-depth knowledge of TeX and later LaTeX. He gave a course for the secretaries of the Institute, the notes of which became the seed for his first German textbook on LaTeX. This led to a series of books, later appearing in English with coauthor and Institute colleague Pat Daly, which were as superb as was his earlier work for the Heating project. Helmut also wrote radar software for a Mars space mission, which, unfortunately, failed during launch.

Helmut retired in 1997, but he remained a regular visitor at the Institute, and continued working on his LaTeX manuals. That the heating facility is still operating in essentially unchanged form, now under the reign of EISCAT, is a testimony to Helmut's abilities. He was a kind, gracious person, always willing to help. He is survived by his wife, two daughters, and grandchildren. He will be missed by his friends and colleagues.

Michael Rietveld
E-mail: mike@eiscat.uit.no

If you wish to receive the Radio Science Bulletin in the URSI triennium 2009-2011 please read this

For the new URSI triennium 2009 - 2011 individuals will get the option to receive the RSB electronically (this will be done by sending an e-mail with a link to the latest issue) or to receive a paper copy. The first option costs 40 Euro and the second option 100 Euro. For more details see the application form on the back cover of this issue.

Everyone who attended the last URSI GA in Chicago, IL, USA (August 2008) had 40 Euro included in the registration fee (and will receive an electronic version of the RSB downloadable from the URSI web site from this March 2009 onwards) except for those who checked a box for a second type of registration fee that costs 60 Euro more. They will still receive a hard copy of the Bulletin

Information for authors

Content

The *Radio Science Bulletin* is published four times per year by the Radio Science Press on behalf of URSI, the International Union of Radio Science. The content of the *Bulletin* falls into three categories: peer-reviewed scientific papers, correspondence items (short technical notes, letters to the editor, reports on meetings, and reviews), and general and administrative information issued by the URSI Secretariat. Scientific papers may be invited (such as papers in the *Reviews of Radio Science* series, from the Commissions of URSI) or contributed. Papers may include original contributions, but should preferably also be of a sufficiently tutorial or review nature to be of interest to a wide range of radio scientists. The *Radio Science Bulletin* is indexed and abstracted by INSPEC.

Scientific papers are subjected to peer review. The content should be original and should not duplicate information or material that has been previously published (if use is made of previously published material, this must be identified to the Editor at the time of submission). Submission of a manuscript constitutes an implicit statement by the author(s) that it has not been submitted, accepted for publication, published, or copyrighted elsewhere, unless stated differently by the author(s) at time of submission. Accepted material will not be returned unless requested by the author(s) at time of submission.

Submissions

Material submitted for publication in the scientific section of the *Bulletin* should be addressed to the Editor, whereas administrative material is handled directly with the Secretariat. Submission in electronic format according to the instructions below is preferred. There are typically no page charges for contributions following the guidelines. No free reprints are provided.

Style and Format

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All papers accepted for publication are subject to editing to provide uniformity of style and clarity of language. The publication schedule does not usually permit providing galleys to the author.

Figure captions should be on a separate page in proper style; see the above guide or any issue for examples. All lettering on figures must be of sufficient size to be at least 9 pt in size after reduction to column width. Each illustration should be identified on the back or at the bottom of the sheet with the figure number and name of author(s). If possible, the figures should also be provided in electronic format. TIF is preferred, although other formats are possible as well: please contact the Editor. Electronic versions of figures *must* be of sufficient resolution to permit good quality in print. As a rough guideline, when sized to column width, line art should have a minimum resolution of 300 dpi; color photographs should have a minimum resolution of 150 dpi with a color depth of 24 bits. 72 dpi images intended for the Web are generally *not* acceptable. Contact the Editor for further information.

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Review Process

The review process usually requires about three months. Authors may be asked to modify the manuscript if it is not accepted in its original form. The elapsed time between receipt of a manuscript and publication is usually less than twelve months.

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